Bacteria Total Maximum Daily Load Development for North River

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CHAPTER 1: EXECUTIVE SUMMARY

1.1. Background

The North River watershed (VAV-B10R through VAV-29R, 523,298 acres) is located in Rockingham and Augusta Counties, Virginia, encompassing the cities of Harrisonburg and Staunton. North River flows east, merges with South River, and discharges into the South Fork of the Shenandoah River (USGS Hydrologic Unit Code 02070005). The South Fork of the Shenandoah River joins with the North Fork of the Shenandoah River to form the Shenandoah River; the Shenandoah River flows into the Potomac River; the Potomac River discharges into the Chesapeake Bay.

1.2. Bacteria Impairment

1.2.1. Background

Water quality samples collected on North River during the 2004 Assessment Period indicated that 29%, 33%, and 37% of the samples collected at stations 1BNTH021.00, 1BNTH022.25, and 1BNTH014.08, respectively, violated the instantaneous water quality standard for bacteria. The instantaneous freshwater water quality standard for fecal coliform specifies that fecal coliform concentration in the stream water should not exceed 400 colony forming units (cfu) per 100 mL; the instantaneous standard for *Escherichia coli* specifies that the *E. coli* concentration should not exceed 235 cfu/100 mL. Due to the frequency of water quality violations at these three stations, North River remained on Virginia's 2004 303(d) list of impaired water bodies for fecal coliform. North River has been assessed as not supporting the Clean Water Act's Swimming Use Support Goal and has been on the 303(d) list since 1996. As listed in the fact sheet, the North River impairment starts at the confluence of North River with Beaver Creek and continues downstream to its confluence with South River. This includes a total of 24.96 stream miles.

In order to remedy the fecal coliform water quality impairment, a Total Maximum Daily Load (TMDL) has been developed, taking into account all sources of bacteria and a margin of safety (MOS). The TMDL was developed for the new water quality standard for bacteria, which states that the calendar-month geometric mean concentration of *E. coli* shall not exceed 126 cfu/100 mL, and that no single sample can exceed a concentration of 235 cfu/100mL. A glossary of terms used in the development of this TMDL is listed in Appendix A.

TMDLs have been previously developed for many of the tributaries to North River (the shaded areas in Figure 1.1). Throughout this report, standard nomenclature will be used to define three areas: the 'entire North River watershed' includes all hydrologic units making up the North River watershed (both the shaded and unshaded areas in Figure 1.1); the 'North River TMDL watershed' includes only those areas without a previously developed TMDL (North River and Briery Branch); and the 'contributing areas' with previously developed TMDLs include the hydrologic units with previously developed TMDLs (Middle River, Moffett Creek, Christians Creek, Mossy Creek, Dry River, Muddy Creek, Long Glade, Cooks Creek, Blacks Run, Pleasant Run, Naked Creek, Mill Creek, and Beaver Creek). Using this nomenclature, allocation scenarios for this TMDL were developed for the North River TMDL watershed. During modeling, detailed hydrology was simulated for the entire North River watershed; detailed bacteria concentrations were simulated only for the North River TMDL watershed. Modeling files from previously developed TMDLs for the contributing areas were used to simulate bacteria for those areas, and the results of those simulations were input to the model for the North River TMDL watershed. Thus, throughout this report, listing of bacteria sources (including permitted facilities) are restricted to the North River TMDL watershed; other types of information will specify whether they are for the entire North River watershed or just the North River TMDL watershed. Approved TMDLs are in place to implement corrective actions to achieve water quality standards in the contributing areas; this report details the further reductions in the North River TMDL watershed that are necessary to meet water quality standards in North River. For this reason, fecal coliform bacteria concentrations from the contributing areas were modeled at the geometric mean standard (200 cfu/100 mL) during allocation scenario generation.

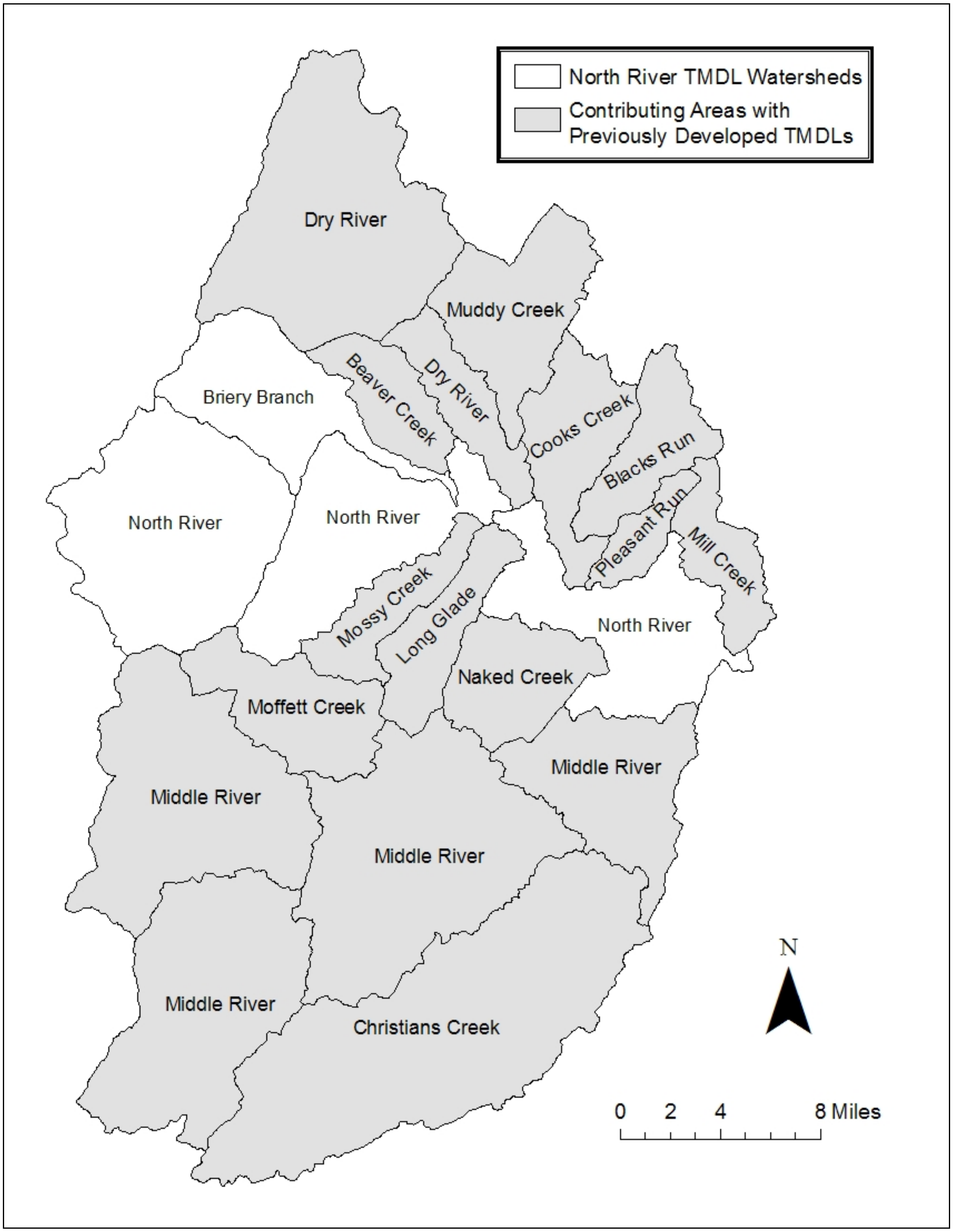

Figure 1.1. Hydrologic Units of the entire North River watershed; shading indicates the existence of a previously developed bacteria TMDL.

1.2.2. Sources of Bacteria

There are sixteen small (1,000 gpd) and two larger point sources permitted to discharge bacteria in the North River TMDL watershed; however, the majority of the bacteria load originates from nonpoint sources. The nonpoint sources of bacteria are mainly agricultural and include land-applied animal waste and manure deposited on pastures by livestock. A significant bacteria load comes from cattle and wildlife directly depositing feces in streams. Wildlife also contribute to bacteria loadings on all land uses, in accordance with the habitat range for each species. Non-agricultural nonpoint sources of bacteria loadings include straight pipes, failing septic systems, and pet waste. The amounts of bacteria produced in different locations (e.g., confinement, pasture, forest) were estimated on a monthly basis to account for seasonal variability in wildlife behavior and livestock production and practices. Livestock management and production factors, such as the fraction of time cattle spend in confinement, pastures, or streams; the amount of manure storage; and spreading schedules for manure application, were considered on a monthly basis.

1.2.3. Modeling

The Hydrological Simulation Program – FORTRAN (HSPF) (Bicknell et al., 2001) was used to simulate the fate and transport of fecal coliform bacteria in the North River watershed. As recommended by VADEQ, water quality modeling was conducted with fecal coliform inputs, and then a translator equation was used to convert the output to *E. coli* for the final TMDL. To identify localized sources of fecal coliform within the watershed, the area of the watershed not covered by a previously developed TMDL was divided into 22 sub-watersheds, based on homogeneity of land use and stream network connectivity. An additional 22 sub-watersheds were delineated in the areas covered by a previously developed TMDL, considering only the stream network.

The hydrology component of HSPF was calibrated using data from September 1, 1985 to August 31, 1990; it was validated using data from September 1, 1990 to December 31, 1994. Initial estimates of hydrologic parameters were generated according to the guidance in BASINS Technical Note

6 (USEPA, 2000a). These parameters were refined during calibration. The program HSPEXP (Expert System for the Calibration of HSPF) was used to aid in calibration, and after the successful calibration the default calibration criteria in HSPEXP were met for both the calibration and validation periods.

The water quality component of the HSPF model was calibrated for North River at three monitoring stations. The bacteria model was calibrated at station 1BNTH036.96 using data from September 1, 1994 to June 30, 2003; at station 1BNTH029.30 with data from August 1, 2001 to June 30, 2003; and at station 1BNTH014.08 with data from September 1, 1993 to February 28, 1995. Inputs to the model included fecal coliform loadings on land and in the stream. A comparison of simulated and observed fecal coliform loadings in the stream indicated that the model adequately simulated the fate and transport of fecal coliform bacteria.

1.2.4. Margin of Safety

A margin of safety (MOS) was included to account for any uncertainty in the TMDL development process. There are several different ways that the MOS could be incorporated into the TMDL (USEPA, 1991). For North River, the MOS was implicitly incorporated into the TMDL by conservatively estimating several factors affecting bacteria loadings, such as animal numbers, bacteria production rates, and contributions to streams.

1.2.5. Existing Conditions

Contributions from various sources in the North River watershed were represented in HSPF to establish the existing conditions for a representative 5-year period that included both low and high-flow conditions. Meteorological data from 1988-1992 were paired with bacterial loading and land use data for existing conditions to establish this baseline scenario. Results of the calibrated HSPF model predict that an estimated 91% of the *E. coli* in the mean daily *E. coli* concentration at the watershed outlet currently comes from areas covered by a previously developed TMDL. Of the remaining 9% of the mean daily *E. coli* concentration, 51% comes from upland contributions of cattle, wildlife, humans, and pets; 23% from wildlife directly depositing in the streams; 19% from cattle directly depositing in the stream; 5% from interflow and groundwater; and 3% from straight pipes directly discharging in the stream. Simulated bacteria concentrations exceeded the calendar-month geometric mean water quality standard 63% of the time at the watershed outlet.

1.2.6. TMDL Allocations and Stage 1 Implementation

Monthly bacteria loadings to different land use categories were calculated for each sub-watershed in each watershed for input into HSPF based on amounts of bacteria produced in different locations. Bacteria content of stored waste was adjusted to account for die-off during storage prior to land application. Similarly, bacteria die-off on land was taken into account, as was the reduction in bacteria available for surface wash-off due to incorporation following waste application on cropland. Direct seasonal bacteria loadings to streams by cattle were calculated for pastures adjacent to streams. Bacteria loadings to streams and land by wildlife were estimated for several species. Bacteria loadings to land from failing septic systems were estimated based on number and age of houses. Bacteria contribution from pet waste was also considered.

When developing a bacteria TMDL, the required bacteria load reductions are modeled by decreasing the amount of bacteria applied to the land surface. In the model, this has the effect of reducing the amount of bacteria that reaches the stream, the ultimate goal of the TMDL. Thus, the reductions called for in Table 1.1 in the next section indicate the need to decrease the amount of bacteria reaching the stream in order to meet the applicable water quality standard. The reductions shown are not intended to infer that agricultural producers should reduce their herd size, or limit the use of manures as fertilizer or soil conditioner. Rather, it is assumed that the required reductions from affected agricultural source categories (cattle direct deposit, cropland, etc.) will be accomplished by implementing BMPs like filter strips, stream fencing, and off-stream watering; and that required reductions from residential source categories will be accomplished by repairing aging septic systems, eliminating straight pipe discharges, and other appropriate measures included in the TMDL Implementation Plan.

For the TMDL allocation scenarios, a target of zero violations of both the instantaneous and geometric mean water quality standards was used. For the Stage 1 implementation scenario, a target of zero reductions in wildlife and 10% violation of the instantaneous standard was used.

1.2.7. Allocation Scenarios

After calibrating to the existing water quality conditions, different source reduction scenarios were evaluated to identify implementable scenarios that meet both the calendar-month geometric mean *E. coli* criterion (126 cfu/100 mL) and the single sample maximum *E. coli* criterion (235 cfu/100 mL) with zero violations. These scenarios were conducted using meteorological data from 1988-1992 to represent a variety of high and low flow conditions. The dates in the allocation graphs correspond to these meteorological years; however, the bacteria loadings used in modeling correspond to anticipated future conditions for the North River watershed. The future conditions were determined by analyzing the Rockingham County Comprehensive Plan (Rockingham County Community Development, 2005). The reductions required in the portion of the North River watershed not covered by a previously developed TMDL are presented in Table 1.1.

Table 1.1. Successful allocation scenarios for the North River TMDL watershed.

Scenario Number	% Violation of *E. coli* standard		Required Fecal Coliform Loading Reductions to Meet the *E coli* Standards,%					
	Geomean	Single Sample	Cattle DD	Loads from Cropland	Loads from Pasture	Wildlife DD	Straight Pipes	Loads from Residential
NR4	0%	0%	50	75	92	0	100	80
NR5	0%	0%	50	90	90	0	100	90

Scenarios NR4 and NR5 meet both *E. coli* standards and would be acceptable targets for implementation. During implementation planning, the implementation plan steering committee could choose either successful scenario upon notification to EPA. The local steering committee that assisted with TMDL development favored a balance of reductions between all land sources; so Scenario NR5 was selected as the recommended allocation scenario. The calculated TMDL loads and associated graphs and tables in this report are for Scenario NR5. This scenario requires a 50% reduction in loadings due to cattle stream access and 100% reduction in straight pipes. It also requires a 90% reduction in loadings originating from the major human-impacted areas: cropland, pasture, and residential. In conjunction with the 90% reduction in surface water loads from the residential area, septic system repairs are expected to reduce the load to groundwater by 50%, returning concentrations in interflow and groundwater to background levels. The concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 1.2 for the TMDL allocation (Scenario NR5), along with the standards.

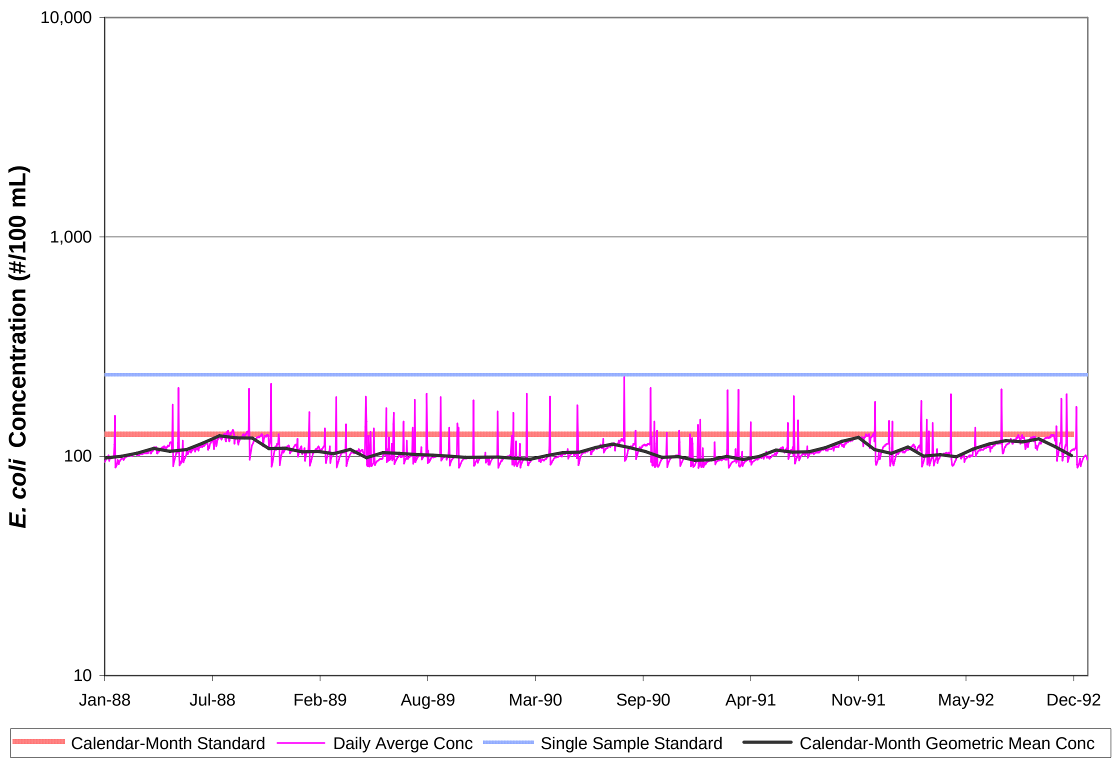

Figure 1.2. Calendar-month geometric mean standard, single sample standard, and successful *E. coli* TMDL allocation (Allocation Scenario NR5).

Equation [1.1] was used to calculate the TMDL allocation shown in Table 1.2.

$$TMDL = \Sigma WLA + \Sigma LA + MOS \qquad [1.1]$$

where:

WLA = wasteload allocation (point source contributions);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety.

There are seven small point sources discharging at or below their permit requirements; therefore, the proposed scenario requires load reductions only for nonpoint sources of fecal coliform. The TMDL was determined as the average annual *E. coli* load at the watershed outlet for the chosen allocation scenario. The WLA was obtained by taking the product of the permitted point source's *E. coli* discharge concentration and allowable annual discharge. The WLA for the MS4 area was determined as the bacteria load at the watershed outlet originating from the MS4 area. The LA is then determined as the TMDL-WLA.

Table 1.2. Annual *E. coli* loadings (cfu/year) at the watershed outlet used for the North River bacteria TMDL.

Parameter	ΣWLA	ΣLA	MOS[a]	TMDL
E. coli	4.97×10^{13} *(Σ16 general permits=2.788×10^{10} VA0060640=4.876×10^{13} VA0022349=8.707×10^{11} VAR040054=9.72×10^{9})*	14.86×10^{13}	--	19.83×10^{13}

[a] Implicit MOS

1.2.8. Stage 1 Implementation

The implementation of a transitional scenario, or Stage 1 implementation, will allow for an evaluation of the effectiveness of management practices and accuracy of model assumptions through data collection. Stage 1 implementation was developed for a maximum of 10% violation rate of the single sample *E. coli* water quality standard (235 cfu/100 mL), based on daily averages of simulated concentrations. In addition, the Stage 1 scenario was designed without reductions from wildlife.

For the North River watershed, successful achievement of TMDLs in the tributaries where they have already been developed should bring the instantaneous standards violations below 10% (Table 1.3). This Stage 1 scenario indicates that implementation of existing TMDLs on North River tributaries will reduce bacteria violation rates in the North River below 10% without additional reductions from the North River TMDL watershed. However, because full implementation of TMDLs on North River tributaries is not yet complete and may not be attained, watershed stakeholders may wish to select alternative or additional implementation milestones during the development of the TMDL IP in order to speed implementation and attainment of water quality goals in the North River itself.

Table 1.3. Allocation scenario for Stage 1 TMDL implementation for the North River TMDL watershed.

Single Sample Standard % Violation	% Reduction Required					
	Cattle DD	Cropland	Pasture	Wildlife DD	Straight Pipes	All Residential PLS
5	0	0	0	0	0	0

1.3. Reasonable Assurance of Implementation

1.3.1. Follow-Up Monitoring

The Department of Environmental Quality (VADEQ) will continue monitoring North River (1BNTH000.18, 1BNTH014.08, 1BNTH036.96) in accordance with its ambient monitoring program to evaluate reductions in fecal bacteria counts and the effectiveness of TMDL implementation in attainment of water quality standards.

1.3.2. Regulatory Framework

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in attainment of water quality standards. This report represents the culmination of that effort for the bacteria impairment on North River. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan and to monitor stream water quality to determine if water quality standards are being attained.

While section 303(d) of the Clean Water Act and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (the "Act") directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of DEQ, DCR, and other cooperating agencies.

Once developed, DEQ intends to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e). In response to a Memorandum of Understanding (MOU) between EPA and DEQ, DEQ also submitted a draft Continuous Planning Process to EPA in which DEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

1.3.3. Implementation Funding Sources

One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. Section 319 funding is a major source of funds for Virginia's Nonpoint Source Management Program. Other funding sources for implementation include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, the Virginia State Revolving Loan Program, and the Virginia Water Quality Improvement Fund. The TMDL Implementation Plan Guidance Manual (VADCR and VADEQ, 2003) contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

1.4. Public Participation

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. In October of 2004, members of the Virginia Tech TMDL development group traveled to Augusta and Rockingham Counties to become acquainted with the watershed. In addition, Virginia Tech personnel contacted stakeholders via telephone to acquire their input. Two public meetings were held. The first public meeting was organized on September 23, 2004 at the John Wayland Elementary School in Bridgewater, Virginia to inform the stakeholders of TMDL development process. The draft TMDL report was discussed at the final public meeting held on November 14, 2005, also at the John Wayland Elementary School. In addition to these public meetings, a local steering committee of interested stakeholders was gathered on two occasions to comment on the TMDL process. During the first local steering committee meeting on October 14, 2004 at the DEQ office in Harrisonburg, the committee members provided feedback on and refinement of the human and animal numbers used in modeling. During the second meeting on September 28, 2005, also located at the DEQ office, the committee members provided feedback on the hydrology and water quality calibrations and the preliminary allocation scenarios.

CHAPTER 2: INTRODUCTION

2.1. Background

2.1.1. TMDL Definition and Regulatory Information

Section 303(d) of the Federal Clean Water Act and the U.S. Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to identify water bodies that violate state water quality standards and to develop Total Maximum Daily Loads (TMDLs) for such water bodies. A TMDL reflects the total pollutant loading a water body can receive and still meet water quality standards. A TMDL establishes the maximum allowable pollutant loading from both point and nonpoint sources for a water body, allocates the load among the pollutant contributors, and provides a framework for taking actions to restore water quality.

2.1.2. Impairment Listing

North River is listed as impaired on Virginia's 2004 Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2004) due to water quality violations of the bacteria standard. The Virginia Department of Environmental Quality (VADEQ) has delineated the impairment on North River on a stream length of 24.96 miles. As described in Virginia's 2004 Section 303(d) report, the impaired stream segment begins at the confluence of North River with Beaver Creek and continues downstream to its confluence with South River. North River is targeted for TMDL development and completion by 2010.

2.1.3. Watershed Location and Description

The North River watershed is a part of the Shenandoah River basin. The main stem of the river is encompassed by three hydrologic units: B16, B17, and B23. Contributing areas to the main stem of the river include B10-B15, B18-B22, and B24-B29. Many of the contributing areas to the North River have previously had bacteria TMDLs developed (Figure 2.1). A complete list of the contributing areas is included in Table 2.1.

There are three classifications of the North River area that will be used throughout the remainder of this report: the entire North River watershed, composed of hydrologic units B10-B29; the North River TMDL watershed, composed of the unshaded area in Figure 2.1 that does not have a previously developed TMDL in place; and the contributing area with previously developed TMDLs, composed of the shaded area in Figure 2.1. For this project, a TMDL was developed for the North River TMDL watershed. Hydrology for this TMDL was modeled and calibrated for the entire North River watershed. Simulated water quality data from the modeling files from previously developed TMDLs were used to represent the bacteria sources from the contributing areas. Thus, a detailed bacteria source assessment and water quality calibration was performed only for the North River TMDL watershed. DEQ will rely on the previously developed TMDLs to achieve water quality standards in the contributing area; this project estimates the additional reductions that will be needed in the North River TMDL watershed in order to meet water quality standards in North River. During allocations, the bacteria from contributing areas with previously developed TMDLs were modeled at the geometric mean water quality standard concentration.

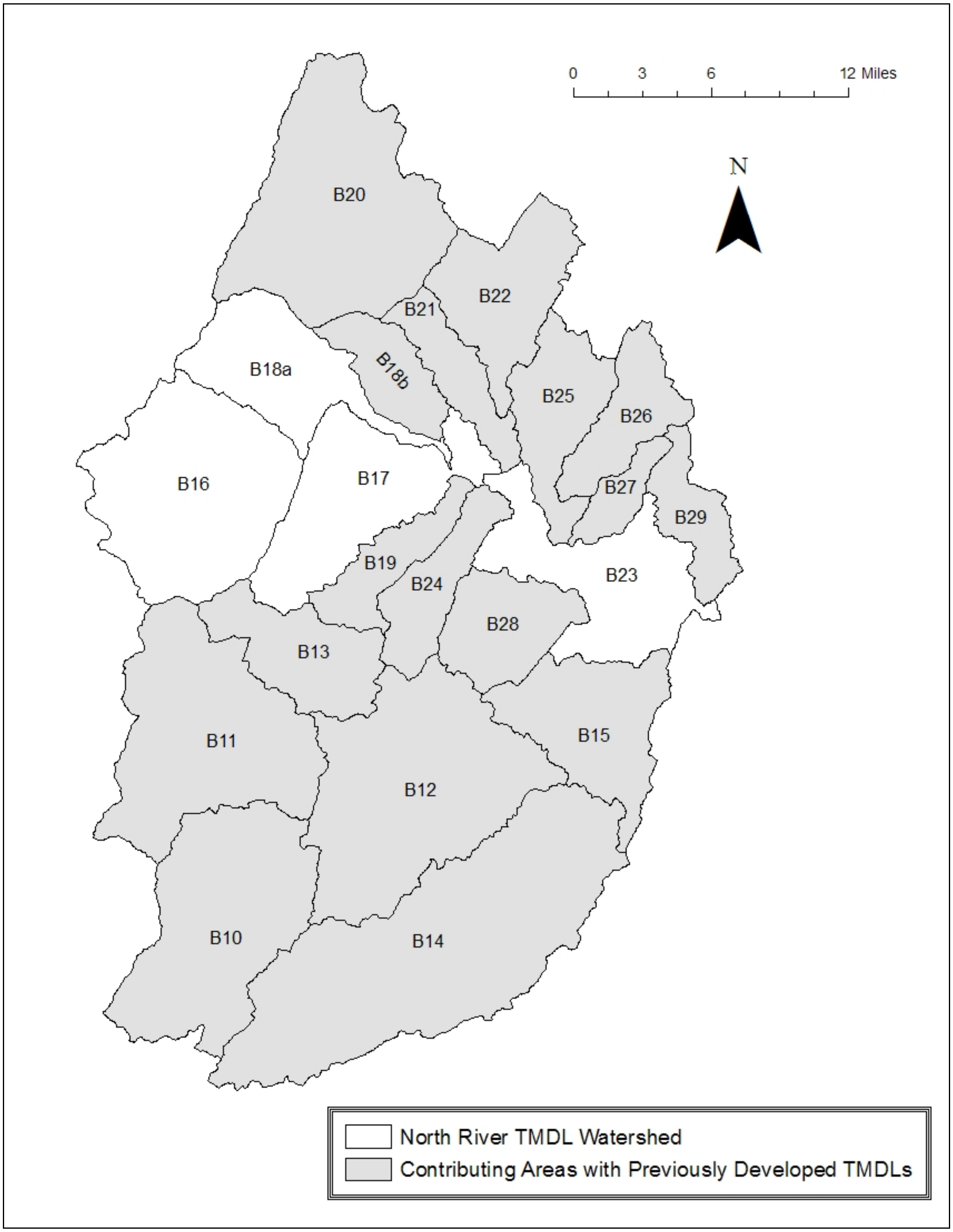

Figure 2.1. Hydrologic Units of the entire North River watershed; shading indicates the existence of a previously developed bacteria TMDL.

Table 2.1. Hydrologic Units in the North River Watershed.

Hydrologic Unit Code	Waterbody Name	Previous Bacteria TMDL Developed?
B10	Upper Middle River	Yes
B11	Middle River/Jennings Branch	Yes
B12	Middle River/Lewis Creek	Yes
B13	Moffett Creek	Yes
B14	Christians Creek	Yes
B15	Lower Middle River	Yes
B16	Upper North River	No
B17	Middle North River	No
B18a	Briery Branch	No
B18b	Beaver Creek	Yes
B19	Mossy Creek	Yes
B20	Upper Dry River	Yes
B21	Lower Dry River	Yes
B22	Muddy Creek	Yes
B23	Lower North River	No
B24	Long Glade Run	Yes
B25	Cooks Creek	Yes
B26	Blacks Run	Yes
B27	Pleasant Run	Yes
B28	Naked Creek	Yes
B29	Mill Creek	Yes

The North River watershed encompasses large portions of Augusta and Rockingham Counties (Figure 2.2). The watershed is 523,298 acres in size. North River as a whole contains nearly equal portions of forest (49%) and pasture (43%) areas. Five percent of the remaining area is in cropland and 4% is distributed among various residential and commercial land uses. Considering only the North River TMDL watershed (hydrologic units with a 'no' in the last column of Table 2.1), forest is the dominating land use (69%), followed by pasture (26%), cropland (4%), and residential (1%) areas. North River flows east, merges with South River, and discharges into the South Fork of the Shenandoah River (USGS Hydrologic Unit Code 02070005). The South Fork of the Shenandoah River joins with the North Fork of the Shenandoah River to form the Shenandoah River; the Shenandoah River flows into the Potomac River; the Potomac River discharges into the Chesapeake Bay.

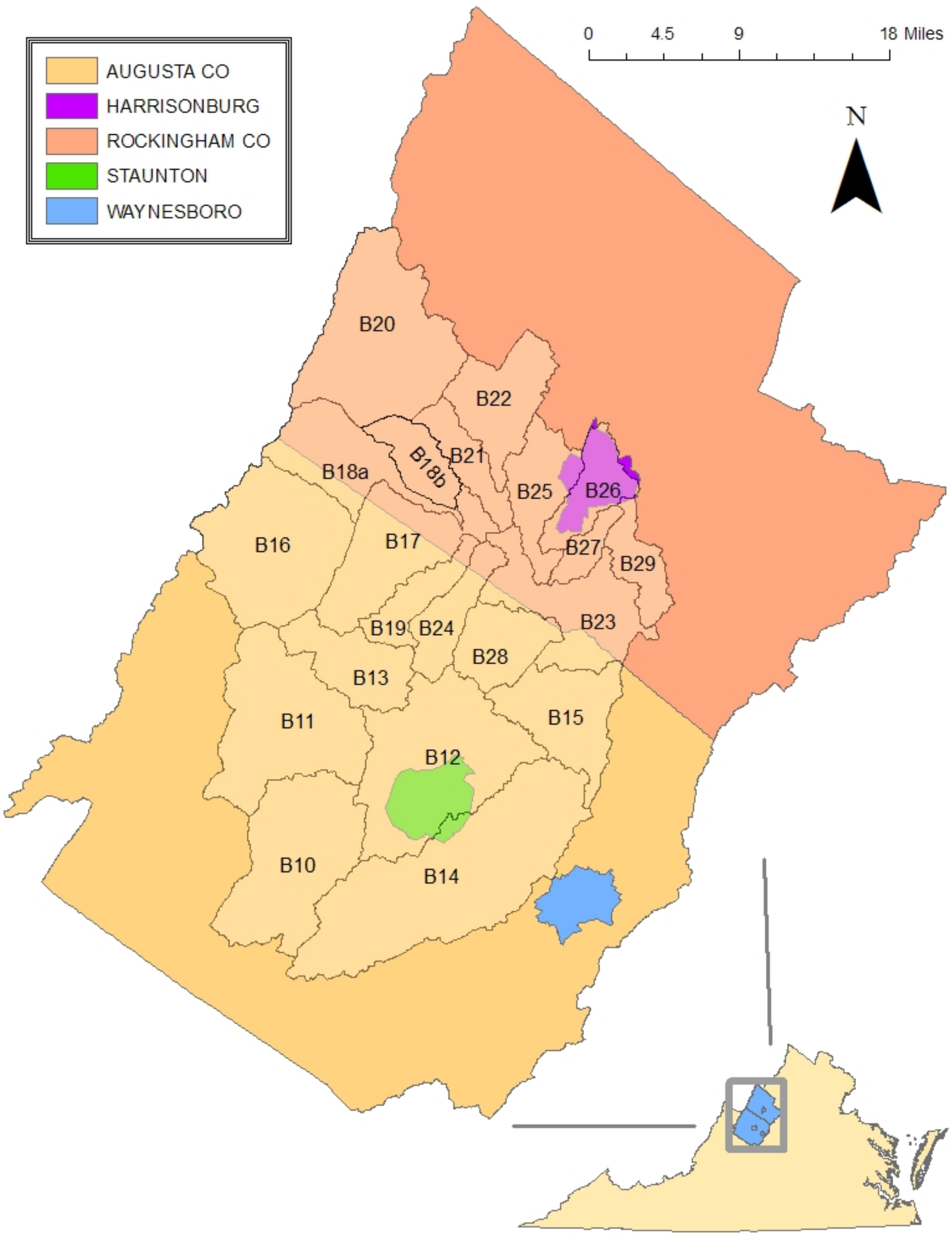

Figure 2.2. Location of the North River watershed.

2.1.4. Pollutants of Concern

Pollution from both point and nonpoint sources can lead to fecal coliform bacteria contamination of water bodies. Fecal coliform bacteria are found in the intestinal tract of warm-blooded animals; consequently, fecal waste of warm-blooded animals contains fecal coliform. Even though most fecal coliform are not pathogenic, their presence in water indicates contamination by fecal material. Because fecal material may contain pathogenic organisms, water bodies with fecal coliform bacteria are potential sources of pathogenic organisms. For contact recreational activities such as boating and swimming, health risks increase with increasing fecal coliform counts. If the fecal coliform concentration in a water body exceeds state water quality standards, the water body is listed for violation of the state bacteria standard for contact recreational uses. As discussed in Section 2.2.2, Virginia has adopted an *Escherichia coli* (*E. coli*) water quality standard. The concentration of *E. coli* (a subset of the fecal coliform group) in water is considered to be a better indicator of pathogenic exposure than the concentration of the entire fecal coliform group in the water body.

2.2. Designated Uses and Applicable Water Quality Standards

2.2.1. Designation of Uses (9 VAC 25-260-10)

> "A. All State waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish." SWCB, 2004.

North River does not support the recreational (swimming) designated use due to violations of the bacteria criteria.

2.2.2. Bacteria Standard (9 VAC 25-260-170)

EPA has recommended that all states adopt an *E. coli* or enterococci standard for fresh water and enterococci criteria for marine waters, because there is a stronger correlation between the concentration of these organisms (*E. coli* and enterococci) and the incidence of gastrointestinal illness than there is with fecal coliform. *E. coli* and enterococci are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals and are subsets of the fecal coliform and fecal streptococcus groups, respectively. In line with this recommendation, Virginia adopted and published revised bacteria criteria on June 17, 2002. The revised criteria became effective on January 15, 2003. As of that date, the *E. coli* standard described below applies to all freshwater streams in Virginia. Additionally, prior to June 30, 2008, the interim fecal coliform standard must be applied at any sampling station that has fewer than 12 samples of *E. coli*.

For a non-shellfish water body to be in compliance with Virginia's revised bacteria standards (as published in the Virginia Register Volume 18, Issue 20) the following criteria shall apply to protect primary contact recreational uses (SWCB, 2004):

Interim Fecal Coliform Standard:

> Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 mL of water for two or more samples over a calendar month nor shall more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100 mL of water.

Escherichia coli Standard:

> *E. coli* bacteria concentrations for freshwater shall not exceed a geometric mean of 126 counts per 100 mL for two or more samples taken during any calendar month and shall not exceed a single sample maximum of 235 cfu/100mL.

During any assessment period, if more than 10% of a station's samples exceed the applicable standard, the stream segment associated with that station is classified as impaired and a TMDL must be developed and implemented to bring the station into compliance with the water quality standard. Three stations on North River show violations of their applicable standards: samples from stations 1BNTH021.00 and 1BNTH022.25 violate the interim fecal coliform standard; samples from 1BNTH014.08 violate the *E. coli* standard. The impaired segment begins at the confluence with Beaver Creek and runs to the confluence with South River. The bacteria TMDL for the impaired segment will be developed to meet the *E. coli* standard. As recommended by VADEQ, the modeling will be conducted with fecal coliform inputs, and then a translator equation will be used to convert the output to *E. coli*.

CHAPTER 3: WATERSHED CHARACTERIZATION

3.1. Water Resources

The North River Watershed was subdivided into 44 sub-watersheds for modeling purposes as discussed in Section 5.2. Flow is monitored in North River at two locations: station USGS 01620500 Is located in the upland area of the watershed (hydrologic unit B16), draining an area of 17.20 mi²; USGS 01622000 Is located midway through the watershed and drains an area of 379 mi². Numerous springs exist throughout the watershed. Two major known springs are Mount Solon Spring in Mossy Creek, which is fed by water from Freemason Run; and Beaver Creek spring in Beaver Creek, which is fed by water from Dry River. Numerous smaller springs are scattered throughout the watershed. Appendix L contains further information on the springs in North River. Additionally, an artificial pathway transports water from the Staunton Dam in Upper North River to Moffett Creek to eventually provide water to the City of Staunton. Aquifers in this watershed are overlain by limestone, carbonate strata with interbedded limestone, dolomite, and calcareous shale (SCS, 1982; Smith and Ellison, 1985).

3.2. Selection of Sub-watersheds

To account for the spatial distribution of fecal coliform sources, the watershed was divided into 44 sub-watersheds as shown in Figure 3.1. Note that the sub-watersheds were not numbered sequentially. The stream network used to help define the sub-watersheds was obtained from TIGER 2000 data. Sub-watersheds for this study were delineated according to two sets of criteria according to the existence of previously developed TMDLs. In contributing areas with previously developed TMDLs, sub-watersheds were delineated at the hydrologic unit scale; additional sub-watersheds were created only to preserve the stream network. This detail was sufficient for hydrologic modeling; further detail was not needed for bacteria modeling, as bacteria in these areas were not modeled directly (as explained in Chapter 5). Several factors were considered in creation of sub-watersheds for the North River TMDL watershed, where TMDLs had not previously been developed. Because loadings of bacteria are believed to be associated with land use activities and the degree of development in the watershed, sub-watersheds were chosen based on uniformity of land use. The junctions of stream segments are useful locations to break sub-watersheds to preserve the contiguity of the stream network. In order to model the areas with a previously developed TMDL correctly, sub-watershed breaks were made in the North River TMDL area every time a watershed with a previously developed TMDL flowed into North River. A third factor that was taken into consideration in delineating the sub-watersheds in the North River TMDL area was the existence of monitoring stations. It is preferable to have a sub-watershed outlet at monitoring station locations in order to calibrate the model chosen for this study (to be discussed in Chapter 5).

During this study, the North River TMDL watershed was explored in detail. This area includes subwatersheds 1-15 and 17-23 (Figure 3.1). Throughout this report, maps will be shown either for the entire North River watershed or for just the North River TMDL watershed, depending on the relevance of the presented information. For example, as hydrology was modeled for the entire watershed, details of land use and soils were important for the entire area; however, bacteria source information is only provided for the North River TMDL watershed.

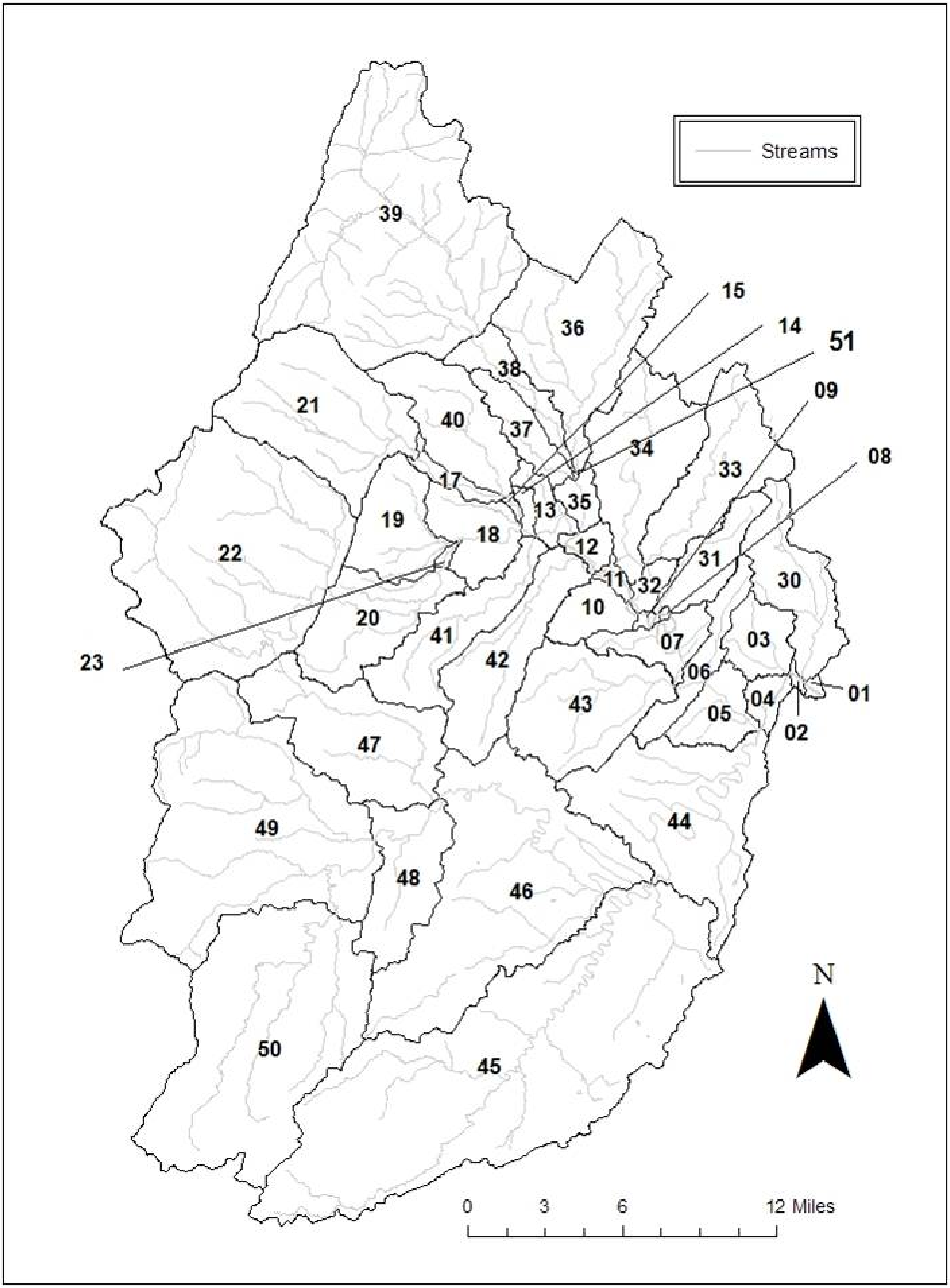

Figure 3.1. North River Sub-Watersheds.

3.3. Ecoregion

The North River watershed is located in the Central Appalachian Ridges and Valleys Level III Ecoregion. Many springs and caves exist in this ecoregion. North River is located primarily in two Level IV Ecoregions: Northern Limestone/Dolomite Valleys and Northern Dissected Ridges. A significant part of the North River watershed is located in the Northern Shale Valleys Level IV Ecoregion, and a small part is located in the Northern Sandstone Ridges Level IV Ecoregion. The ridges in the Level III Ecoregion tend to be forested, while limestone valleys are composed of rich agricultural land (USEPA, 2003). The Northern Limestone/Dolomite Valleys Level IV ecoregion has fertile land and is primarily agricultural. The Northern Dissected Ridges region is composed of broken ridges and knobs, and is primarily covered by forest. The Northern Shale Valleys ecoregion has less productive, more acidic land and a tendency toward wider streams than the limestone valleys. The Northern Sandstone Ridges contain straight, continuous ridges (as opposed to the Dissected Ridges region) and are covered primarily with oak forests (Woods et al., 1999).

3.4. Soils and Geology

Five State Soil Geographic (STATSGO) soil groups are found in the North River watershed (Figure 3.2). The Berks-Weikert-Laidig association is found in the Northern Shale Valleys ecoregion and is characterized by well-drained soils with a loamy subsoil, underlain by shale. The second association is Carbo-Chilhowie-Frederick, characterized by moderately deep to deep, well-drained soils with a clayey subsoil, underlain by limestone. The third association is Frederick-Carbo-Chilhowie, found in the Northern Limestone/Dolomite Valleys ecoregion and occupying the majority of the valley area in North River. This association is characterized by deep, well drained soils with clayey subsoils, underlain by limestone or dolomite. The fourth major association is Moomaw-Jefferson-Alonzville, characterized by deep soils of varying drainage found along streams and in floodplains. The final soil association found in North River is Wallen-Dekalb-Drypond, found in the Northern Dissected Ridges ecoregion and occupying the majority of the mountainous area in North River. This association is characterized by moderately deep to deep, well drained soils found in mountainous uplands with loamy or channery subsoils (SCS and FS, 1979; SCS, 1982).

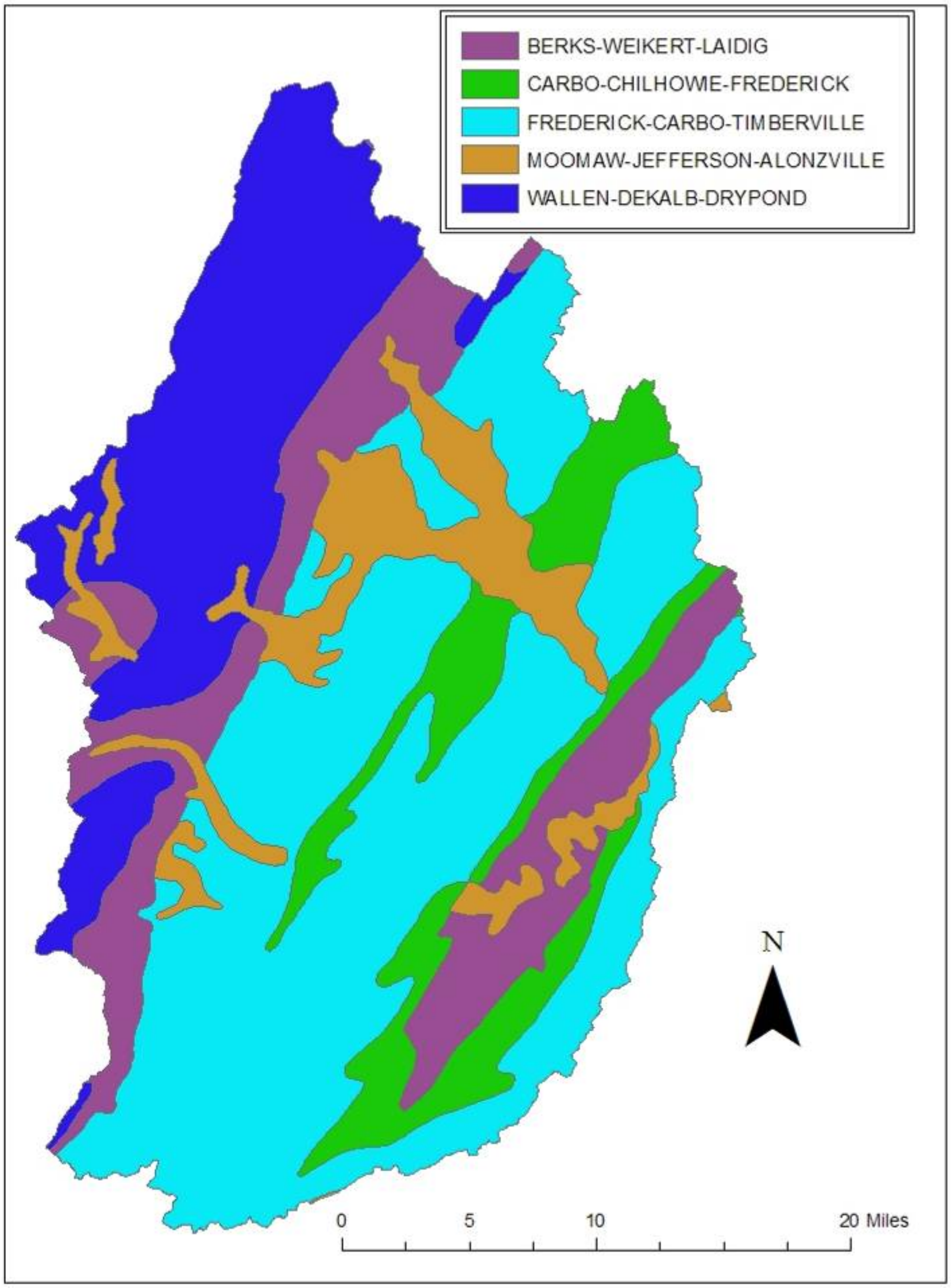

Figure 3.2. STATSGO soil groups in the North River watershed.

3.5. Climate

The climate of the watershed is characterized based on the meteorological observations acquired at “nearby” weather stations including Dale Enterprise (Virginia), Lynchburg Airport (Virginia), and Elkins Airport (West Virginia). The long-term record summary (8/1/1948-3/31/2004) available for the nearby Dale Enterprise station at the Southeast Regional Climate Center shows average annual precipitation to be 35.57 in., with 59% of the precipitation occurring during the cropping season (May-October). Average annual snowfall at Dale Enterprise is 24.6 in., with the highest snowfall occurring during February. Average annual daily temperature is 53.3°F. The highest average daily temperature of 73.7°F occurs in July while the lowest average daily temperature of 32.3°F occurs in January (SERCC, 2004).

3.6. Land Use

From the 1992 National Land Cover Dataset (NLCD) (USGS, 2005), land uses in North River were grouped into five major categories based on similarities in hydrologic features and waste application/production practices (Table 3.1). Using these groupings, forest is the main land use category in the North River watershed, comprising 49% of the total watershed area and 69% of the area not covered by a previously developed TMDL. The remainder of the watershed is primarily pasture (43% whole watershed/26% no TMDL). Smaller areas of cropland exist (5% whole watershed/4% no TMDL). Residential and rural developments cover 4% of the total watershed area and 1% of the area not covered by a previously developed TMDL, and are primarily clustered near Harrisonburg and Bridgewater to the north and Staunton to the south. The five land use categories were assigned pervious and impervious percentages for use in the watershed model. Land uses for the North River watershed are presented graphically in Figure 3.3. Land uses are tabulated for the area of North River not covered by a previously developed TMDL in Table 3.2, and for the remaining area in Table 3.3.

Table 3.1. Consolidation of NLCD land use for the entire North River watershed.

TMDL Land Use Categories	Pervious/Impervious[a] (Percentage)	NLCD Land Use Categories (Class No.)
Cropland	Pervious (100%)	Row Crops (82)
Pasture	Pervious (100%)	Pasture/Hay (81)
Low Density Residential	Pervious (70%) Impervious (30%)	Low Intensity Residential (21) Transitional (33)
High Density Residential	Pervious (50%) Impervious (50%)	Commercial/Industrial/Transport (23)
Forest	Pervious (100%)	Open Water (11) Deciduous Forest (41) Evergreen Forest (42) Mixed Forest (43) Woody Wetlands (91) Emergent Herbaceous Wetlands (92)

[a] Percent perviousness/imperviousness information was used in modeling (described in Section 5.4)

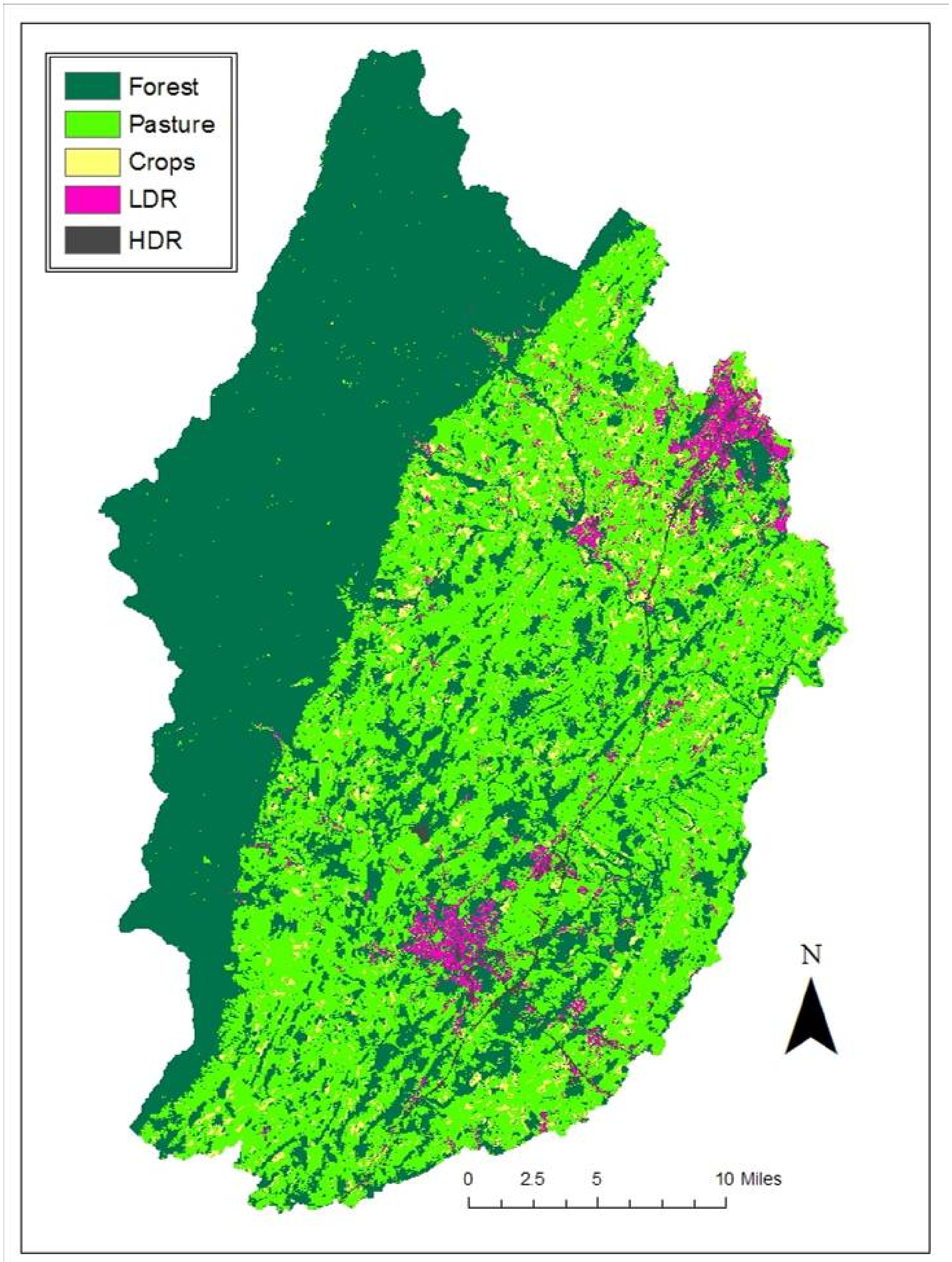

Figure 3.3. North River Watershed Land Use.

Table 3.2. Land use distribution in the North River TMDL watershed (acres).

Sub-watershed	Forest	HDR	LDR	Pasture	Cropland
1	110	0	1	213	3
2	63	0	0.2	168	17
3	584	0	33	3,421	308
4	525	0	0.2	1,039	165
5	766	7	94	3,182	477
6	1,102	81	162	3,013	329
7	1,340	5	38	2,607	348
8	44	0	2	66	2
9	113	30	28	94	67
10	917	5	23	2,370	299
11	156	12	69	430	104
12	429	90	466	514	121
13	398	14	44	1,393	400
14	68	2	2	466	209
15	56	2	10	165	28
17	853	1	44	506	151
18	1,220	5	80	3,956	823
19	4,750	3	35	2,891	408
20	6,659	19	78	3,298	759
21	19,439	34	11	87	9
22	41,405	37	2	48	5
23	62	1	0	215	26

Table 3.3. Land use distribution in the contributing areas with a previously developed TMDL (acres).

Sub-watershed	Forest	HDR	LDR	Pasture	Cropland
30	1,874	6	453	6,470	827
31	1,000	28	217	3,459	602
32	90	86	94	891	280
33	2,589	1,376	3,389	4,003	873
34	1,824	226	1,272	9,264	1,876
35	319	48	85	1,103	283
36	7,696	31	328	10,648	1,305
37	813	11	127	2,676	435
38	2,482	6	121	1,212	290
39	46,492	0.2	8	92	11
40	6,168	4	93	3,485	374
41	2,361	2	87	7,062	558
42	2,232	1	44	8,953	634
43	4,719	37	78	9,201	636
44	4,388	181	305	16,530	1,270
45	21,068	1,497	1,628	40,827	3,729
46	11,775	1,163	3,754	20,853	1,342
47	8,176	1	37	8,275	652
48	3,728	188	202	5,695	267
49	31,420	10	318	9,274	748
50	13,686	1	114	24,093	1,807
51	31	0	0.2	11	0.4

3.7. Stream Flow Data

Two continuous stream flow monitoring stations were located on North River (Figure 3.4). The first, USGS 01620500, North River near Stokesville, is located in the upland area of the watershed (hydrologic unit B16), draining an area of 17.20 mi². This station's record spans 1946 to present. Its average flow rate since 1980 is 28 cfs. The second station, USGS 01622000, North River near Burketown, VA, is located midway through the watershed (the outlet of sub-watershed 8, Figure 3.1) and drains an area of 379 mi². Data from this station were available from 1926 to present. The average flow rate at this station since 1980 is 417 cfs. A hydrologic calibration and validation was performed using data from station 01622000, as this station drained a larger portion of the watershed.

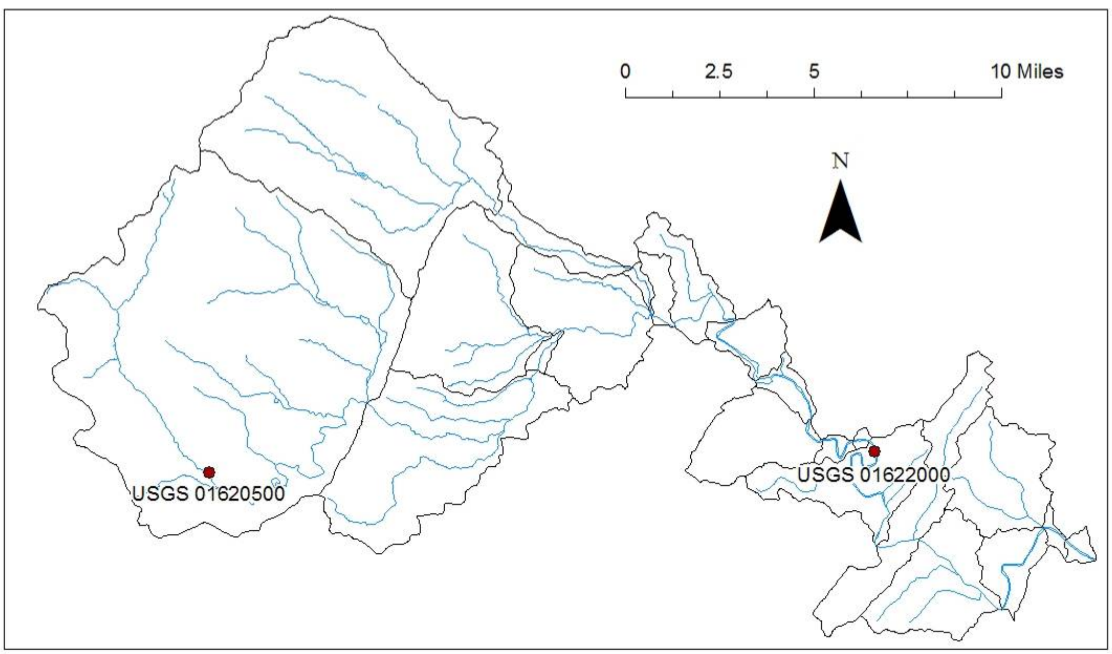

Figure 3.4. Location of USGS flow gaging stations on North River.

3.8. Water Quality Data

The Virginia DEQ (VADEQ) monitored North River water quality at numerous stations with varying periods of record. Water quality data were recorded for at least one station on North River from 1968 to the present. The main monitoring station, where the longest continuous record exists, is 1BNTH014.08, collocated with the flow gage USGS 01622000 at the outlet of subwatershed 8. The locations of all monitoring stations on North River are shown in Figure 3.5; their periods of record are shown in Table 3.4.

The assessment on North River shows a potential for nonpoint source pollution from agricultural and wildlife sources. From January 1998 to December 2002, 15 of 51 fecal coliform samples at station 1BNTH021.00, 3 of 9 fecal coliform samples at station 1BNTH022.25, and 10 of 27 *E. coli* samples at station 1BNTH14.08 exceeded their respective standards (400 cfu/100 mL fecal coliform and 235 cfu/100 mL *E. coli*). Consequently, North River was assessed as not supporting the Clean Water Act's Swimming Use Support Goal for the 2004 305(b) report and was included in the 2004 303(d) list (VADEQ, 2004). Figure 3.6, Figure 3.7, and Figure 3.8 show the bacteria concentrations at each station used for listing, along with the allocation period and appropriate standards and caps. During the period used for calibration (September 1, 1993 to February 28, 1995), a total of 18 fecal coliform samples were taken at station 1BNTH014.08, 11 of which violated the 400 cfu/100 mL instantaneous standard.

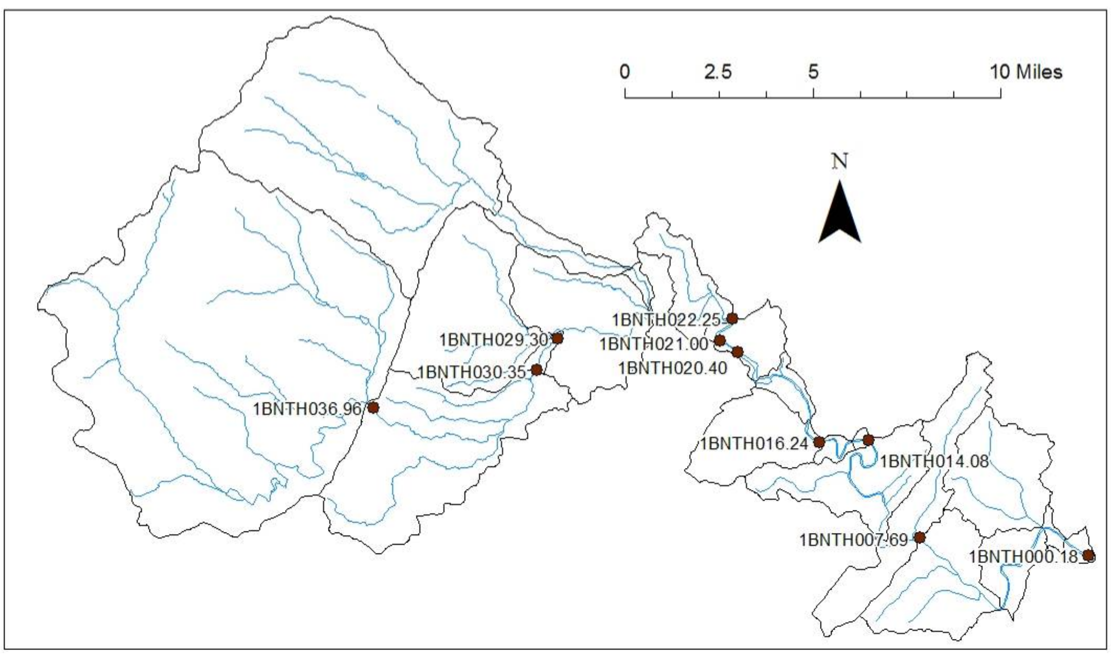

Figure 3.5. DEQ Water Quality Monitoring Stations on North River.

Table 3.4. Water quality stations reporting bacteria concentrations in North River. Periods of record are for fecal coliform unless otherwise noted.

Station ID	Period of Record
1BNTH000.18	Fecal coliform: 7/7/1968-3/1/1979; 7/11/2001-present *E. coli:* 11/17/03-present
1BNTH007.69	7/11/2001-5/1/2003
1BNTH014.08	Fecal coliform: 1/8/1978-present *E. coli*: 1/11/2000-present
1BNTH016.24	7/7/1968-3/5/1979
1BNTH020.40	3/2/1970-3/5/1979
1BNTH021.00	8/4/1998-6/18/2003
1BNTH022.25	8/12/1996-5/19/1997; 8/6/2001-6/18/2003
1BNTH029.30	8/20/2001-6/18/2003
1BNTH030.35	7/28/1993-4/8/1997
1BNTH036.96	Fecal coliform: 9/7/1994-6/18/2003 *E. coli*: 8/5/2004-present

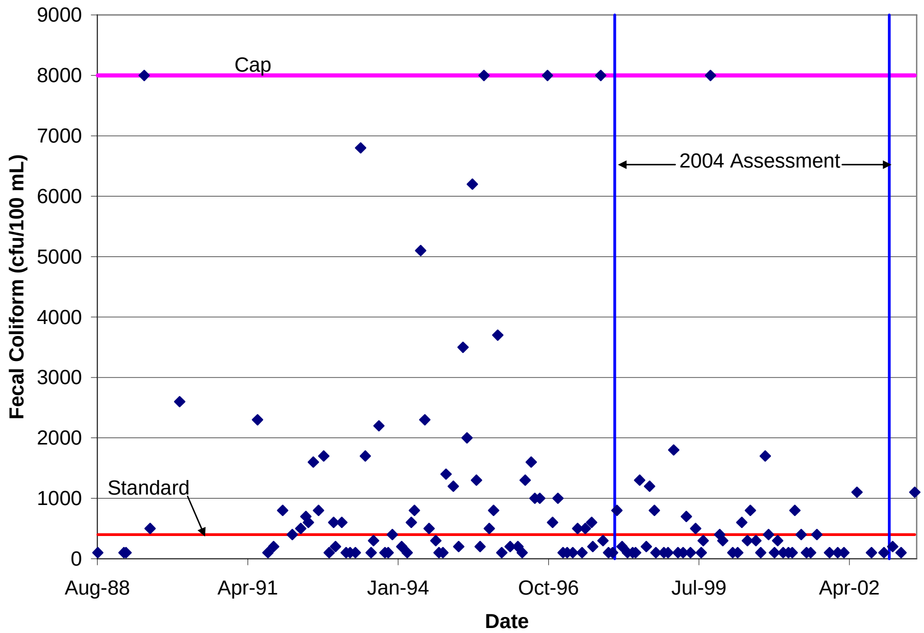

Figure 3.6. Time series of fecal coliform concentration in North River at station 1BNTH021.00.

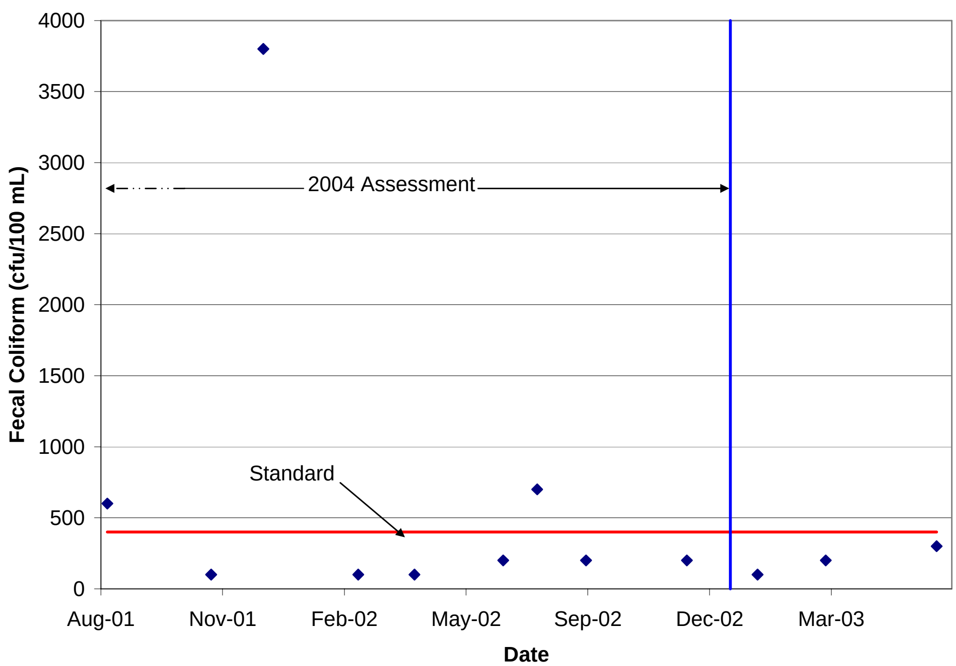

Figure 3.7. Time series of fecal coliform concentration in North River at station 1BNTH022.25.

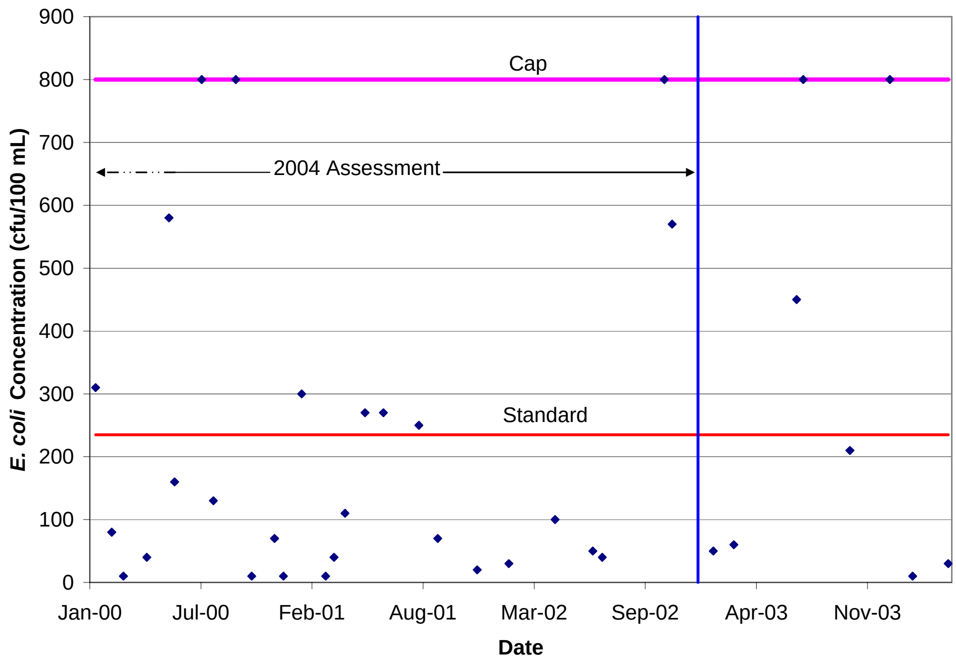

Figure 3.8. Time series of *E. coli* concentration in North River at station 1BNTH014.08.

The Membrane Filter Method (MFM) was used for the analysis of the bacteria samples presented in the previous figures. The fecal coliform samples analyzed with this method and reported here had caps of 8,000 cfu/100 mL. The *E. coli* samples analyzed with this method had caps of 800 cfu/100 mL.

Seasonality of fecal coliform concentration in the streams was evaluated by plotting the mean monthly fecal coliform concentration values observed at station 1BNTH014.08 (

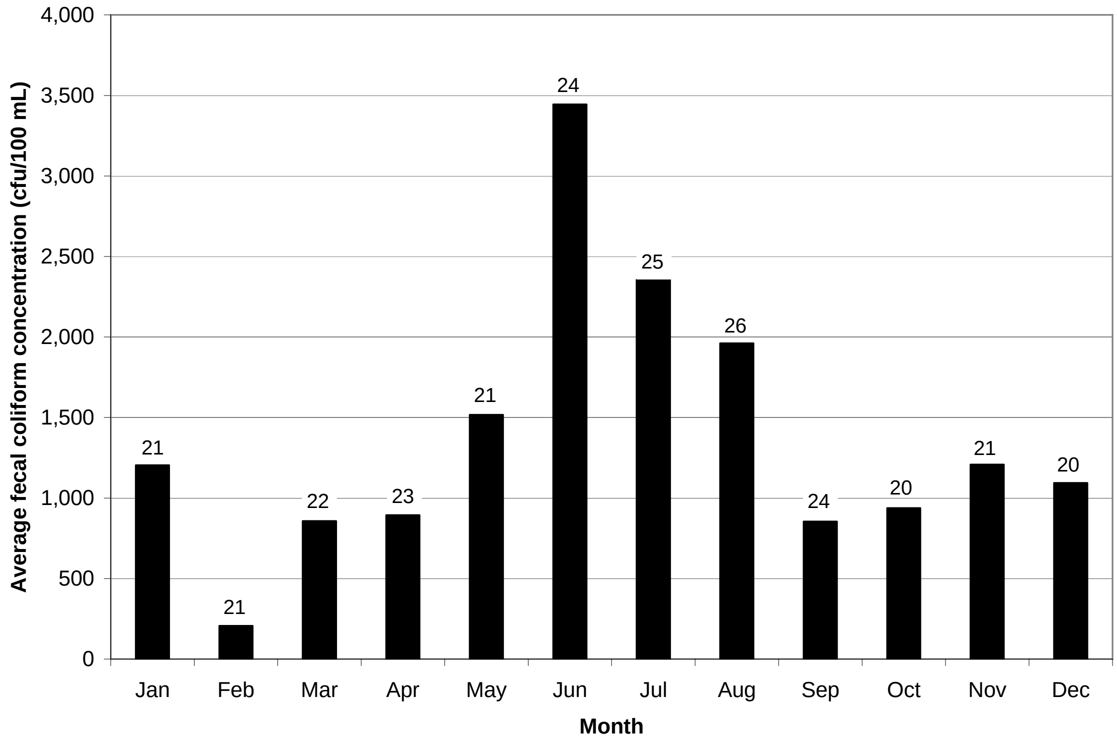

Figure 3.9). Mean monthly fecal coliform concentration was determined as the average of twenty to twenty-six values for each month; the number of values varied according to the available number of samples for each month in the 1978 to 2003 period of record.

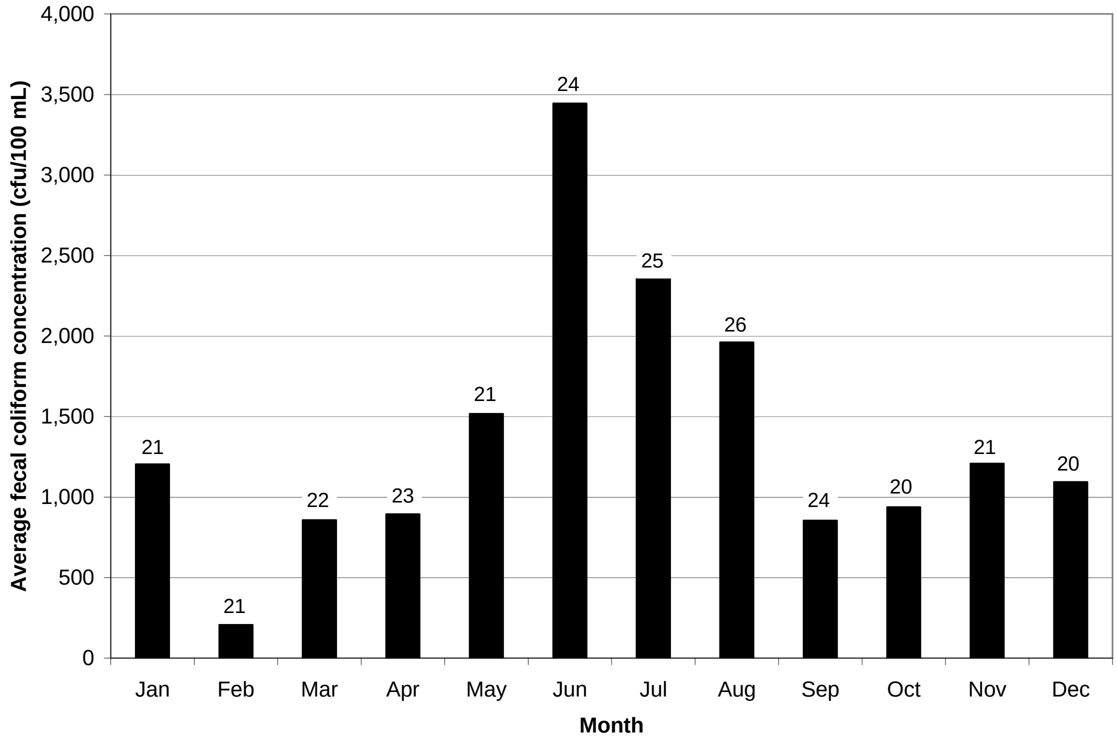

Figure 3.9. Impact of seasonality on fecal coliform concentrations in North River at station 1BNTH014.08 (numbers at top of bars indicate the number of samples contributing to the average).

The data indicate seasonal variability with higher in-stream fecal coliform concentrations occurring during the summer months and rather steady, lower concentrations in other months. February is the only real outlier to this trend, with much lower observed values. During the four months with higher values (May - August, primarily the summer months), the average fecal coliform concentration was 2,338 cfu/100mL compared with 1,002 cfu/100mL during the remaining months other than February (September - January, March-April). February weighed in at 206 cfu/100 mL. It should be noted that the cap on fecal coliform concentrations recorded at station 1BNTH014.08 varied between 2,000; 8,000; 16,000; and 24,000; thus, the actual counts could be much higher when fecal coliform levels are equal to these maximum levels, increasing the averages shown in

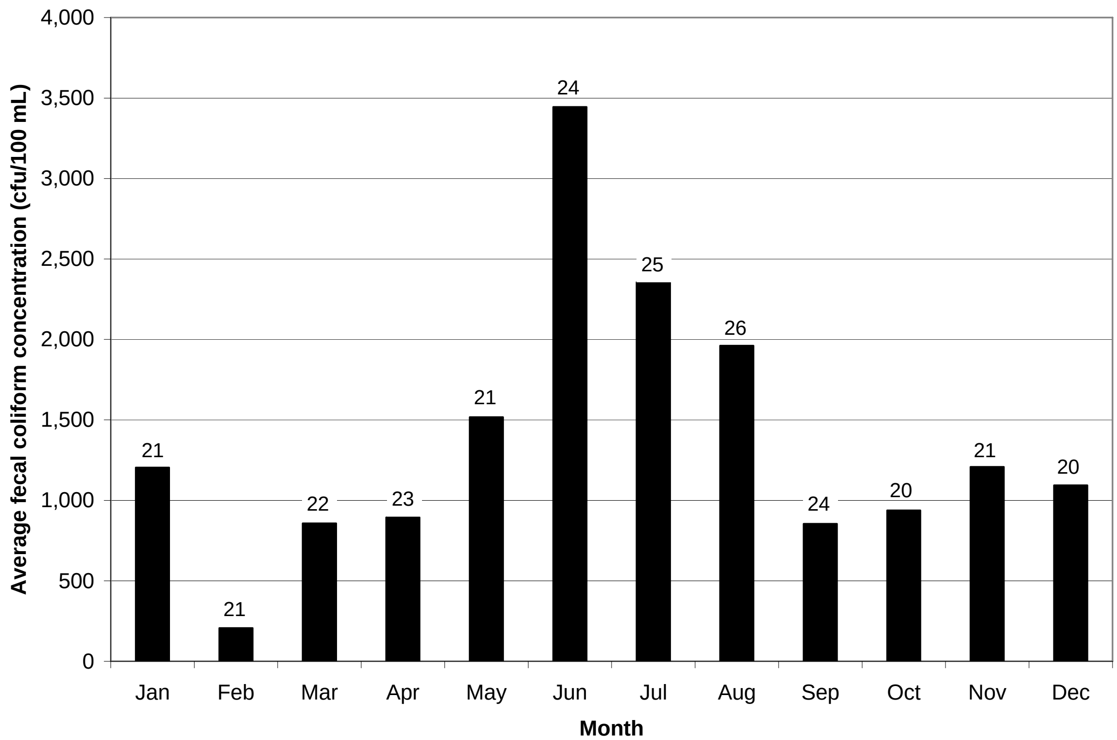

Figure 3.9.

CHAPTER 4: SOURCE ASSESSMENT OF FECAL COLIFORM

Fecal coliform sources in the North River TMDL watershed were assessed using information from the following sources: VADEQ, VADCR, Virginia Department of Game and Inland Fisheries (VADGIF), Virginia Department of Agricultural and Consumer Services (VDACS), Virginia Cooperative Extension (VCE), NRCS, public participation, watershed reconnaissance and monitoring, published information, and professional judgment. Point sources and potential nonpoint sources of fecal coliform are described in detail in the following sections and summarized in Table 4.1 and Table 4.2. All of the sources discussed in this Chapter are only for the North River TMDL watershed and not the contributing areas with previously developed TMDLs.

Point sources of fecal coliform bacteria in the North River TMDL watershed include wastewater treatment plants and private residences that fall under general permits. Virginia issues Virginia Pollutant Discharge Elimination System (VPDES) permits for point sources of pollution. In Virginia, point sources that treat human waste are required to maintain a fecal coliform concentration of 200 cfu/100 mL or less in their effluent. There were 16 general permits (indicated by 'VAG' in the permit number) and three VPDES dischargers in the North River TMDL watershed, as detailed in Table 4.2. In allocation scenarios for bacteria, the entire allowable point source discharge concentration of 200 cfu/100 mL was used.

Additionally, a Phase II municipal separate storm sewer system (MS4) permit has been issued in for the Town of Bridgewater (VAR040054). This permit is designed to compel awareness of the quality of water discharging from publicly owned storm sewer outfalls, and to reduce pollution from the MS4, although no numerical limits for any specific water quality parameter are stipulated in these permits. The permit blurs the lines that have traditionally distinguished point and nonpoint sources of pollution. While MS4 permits are regulated similarly to point source discharges, water quality discharging from MS4s is nearly exclusively dictated by nonpoint source runoff (along with an unknown, but presumed small, amount of illicit connections). Fecal coliform loads modeled from impervious areas within the MS4 area are included in the wasteload allocation (WLA) component of the TMDL, in compliance with 40 CFR §130.2(h). Fecal coliform loads related to stormwater runoff from areas covered by the MS4 permit were modeled with HSPF as contributions from impervious land use categories.

Table 4.1. Potential fecal coliform sources and daily fecal coliform production by source in North River TMDL watershed.

Potential Source	Population in Watershed	Fecal coliform produced ($\times 10^6$ cfu/head-day)
Humans	11,166	1,950[a]
Dairy cattle		
Milk and dry cows	4,482	20,200[b]
Heifers [c]	2,526	9,200[d]
Beef cattle	1,936	20,000
Pets	4004	450[e]
Poultry		
Chicken Broilers	2,320,000	136[f]
Chicken Pullets	33,000	27[g]
Turkeys	870,100	93[h]
Ewes	739	12,000[f]
Horses	419	420[f]
Deer	5,555	350
Raccoons	2,236	50
Muskrats	1,757	25[h]
Beavers	119	0.2
Wild Turkeys	1,161	93[f]
Ducks[i]	868; 619	800
Geese[i]	1,004; 743	2,400

[a] Source: Geldreich (1978)
[b] Based on data presented by Metcalf and Eddy (1979) and ASAE (1998)
[c] Includes calves
[d] Based on weight ratio of heifer to milk cow weights and fecal coliform produced by milk cow
[e] Source: Weiskel *et al.* (1996)
[f] Source: ASAE (1998)
[g] Based on bacteria concentration in chicken manure (ASAE(1998)) and relative manure production by pullets and chickens
[h] Source: Yagow (2001)
[i] population given as summer, winter population

Table 4.2. Permitted facilities discharging into streams of the North River TMDL watershed.

Permit Number	Facility Name	Sub-Watershed	Design Flow (gpd)	Permitted FC Conc. (cfu/100 mL)	FC Load (cfu/year)
VA0051420	Bridgewater WTP	NR-12	0.0223×10^6	--	--
VA0060640	North River WWTP	NR-09	28×10^6	200	$7.74*10^{13}$
VA0022349	Weyers Cave STP	NR-05	0.5×10^6	200	$1.38*10^{12}$
VAG401207	Homeowner	NR-06	1000	200	$2.76*10^9$
VAG401223	Homeowner	NR-17	1000	200	$2.76*10^9$
VAG401269	Church	NR-06	1000	200	$2.76*10^9$
VAG401341	Homeowner	NR-07	1000	200	$2.76*10^9$
VAG401643	Homeowner	NR-20	1000	200	$2.76*10^9$
VAG401688	Homeowner	NR-04	1000	200	$2.76*10^9$
VAG401692	Homeowner	NR-22	1000	200	$2.76*10^9$
VAG401720	Homeowner	NR-20	1000	200	$2.76*10^9$
VAG401745	Homeowner	NR-19	1000	200	$2.76*10^9$
VAG401774	Homeowner	NR-19	1000	200	$2.76*10^9$
VAG401869	Homeowner	NR-20	1000	200	$2.76*10^9$
VAG401985	Homeowner	NR-13	1000	200	$2.76*10^9$
VAG408101	Homeowner	NR-18	1000	200	$2.76*10^9$
VAG408156	Homeowner	NR-18	1000	200	$2.76*10^9$
VAG408161	Homeowner	NR-21	1000	200	$2.76*10^9$
VAG408181	Homeowner	NR-18	1000	200	$2.76*10^9$

4.1. Humans and Pets

The North River TMDL watershed has an estimated population of 11,166 people (4004 households at an average of 2.79 people per household; actual people per household varies by sub-watershed). Fecal coliform from humans can be transported to streams from failing septic systems or via straight pipes discharging directly into streams.

4.1.1. Failing Septic Systems

Septic system failure can be evidenced by the rise of effluent to the soil surface. Surface runoff can transport the effluent containing fecal coliform to receiving waters. It was estimated that 1,623 houses in the North River TMDL watershed are connected to a sewer line. These sewered areas are located in sub-watersheds 5, 6, 11, and 12. Unsewered households were located using E-911 digital data obtained from the GIS Coordinator for Rockingham County Community Development in November 2004. Each unsewered household was classified into one of three age categories (pre-1960s, 1960s-1980s, and post-1980s) based on appropriate USGS 7.5-min. topographic maps, which were initially created using photographs from the 1960s and were photo-revised in the 1980s. It was assumed that septic system failure rates for houses in the pre-1960s, 1960s-1980s, and post-1980s age categories were 40, 20, and 3%, respectively (R.B. Reneau, personal communication, 3 December 1999, Blacksburg, Va.). Estimates of these failure rates were also supported by the Holmans Creek Watershed Study (a watershed located in Rockingham County), which found that over 30% of all septic systems checked in the watershed were either failing or not functioning at all (SAIC, 2001).

Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average occupancy rate for that sub-watershed (occupancy rate ranged from 2 to 3 persons per household (Census Bureau, 2000)) by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich, 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a sub-watershed with an occupancy rate of 1 person/household was 1.95×10^9 cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur. The number of failing septic systems in the watershed is given in Table 4.3. Additionally, to account for failing septic systems that might be failing downward, the bacteria concentration in interflow and groundwater from residential areas was set to 60 and 40 cfu/100 mL, respectively. There was not much information in the literature regarding bacteria concentrations in subsurface water in rural residential areas. Pasquarell and Boyer (1995) and Boyer (2005) reported fecal coliform bacteria concentrations in groundwater in a primarily agricultural basin in West Virginia. In the basin with the most rural residential area (Davis Spring), the median fecal coliform bacteria concentrations in groundwater reported by these two studies were 45 and 53 cfu/100 mL, respectively (range <1 to 5,200 cfu/100 mL). The 40 and 60 cfu/100 mL concentrations were arrived at by considering this information, the fact that a concentration needed to be considered for both interflow and groundwater, DEQ's guidance that states interflow concentrations should be 50% greater than groundwater concentrations (VADEQ, 2003), and input from the local steering committee.

4.1.2. Straight Pipes

Of the houses located within 150 ft of streams, in the pre-1960s and 1960s-1980s age categories, 10%, and 2%, respectively, were estimated to have straight pipes (R.B. Reneau, personal communication, 3 December 1999, Blacksburg, Va.). Based on these criteria, it was estimated that four North River sub-watersheds had one straight pipe each: sub-watersheds 18, 19, 20, and 21.

4.1.3. Pets

Assuming one pet per household, there are 4004 pets in North River TMDL watershed. A dog produces fecal coliform at a rate of 0.45×10^9 cfu/day (Weiskel et al., 1996); this was assumed to be representative of a 'unit pet' – one dog or several cats. The pet population distribution among the sub-watersheds is listed in Table 4.3. Pet waste is generated in the rural residential areas. Surface runoff can transport bacteria in pet waste from residential areas to the stream.

Table 4.3. Estimated number of sewered houses and unsewered houses by age category, number of failing septic systems, and pet population in the North River TMDL watershed.

Sub-watershed	Sewered houses (no.)	Unsewered houses in each age category (no.)				Failing septic systems (no.)	Pet population[a]
		Straight Pipes	Pre-1960s	1960s-1980s	Post-1980s		
NR-01	0	0	17	5	4	8	26
NR-02	0	0	3	4	3	2	10
NR-03	0	0	74	42	55	40	171
NR-04	0	0	16	14	39	10	69
NR-05	364	0	58	22	45	29	489
NR-06	165	0	80	89	80	52	414
NR-07	0	0	101	85	96	60	282
NR-08	0	0	4	1	1	2	6
NR-09	0	0	3	2	3	2	8
NR-10	8	0	46	38	30	27	122
NR-11	59	0	10	9	3	6	81
NR-12	1027	0	10	2	8	5	1047
NR-13	0	0	44	20	59	23	123
NR-14	0	0	11	10	11	7	32
NR-15	0	0	5	1	1	2	7
NR-17	0	0	51	17	102	27	170
NR-18	0	1	126	45	129	63	300
NR-19	0	1	96	25	88	46	209
NR-20	0	1	192	26	207	88	425
NR-21	0	1	53	19	122	29	194
NR-22	0	0	6	0	4	3	10
NR-23	0	0	3	3	4	2	10
Total	1623	4	1009	479	1094	533	4004

[a] Assumed an average of one pet per household.

4.2. Cattle

Fecal coliform in cattle waste can be directly excreted to the stream, or it can be transported to the stream by surface runoff from animal waste deposited on pastures or applied to crop, pasture, and hay land.

4.2.1. Distribution of Dairy and Beef Cattle in the North River TMDL Watershed

There are 38 dairy farms in the watershed, based on reconnaissance and information from VDACS. From communication with local dairy farmers, it was determined that there are 3911 milk cows, 571 dry cows, and 2526 heifers in the watershed (Table 4.1). The dairy cattle population was distributed among the sub-watersheds based on the location of the dairy farms. Table 4.4 shows the number of dairy operations for each sub-watershed.

Table 4.4. Distribution of dairy cattle, dairy operations and beef cattle among North River sub-watersheds.

Sub-watershed[a]	Dairy cattle	No. of dairy operations[a]	Beef cattle
NR-01	0	0	13
NR-02	0	0	10
NR-03	115	1	199
NR-04	0	0	59
NR-05	1,730	3	232
NR-06	0	0	198
NR-07	1,011	4	157
NR-08	0	0	4
NR-09	0	0	6
NR-10	285	2.5	151
NR-11	73	0.5	25
NR-12	0	0	31
NR-13	1,073	7.1	84
NR-14	318	2	27
NR-15	264	2.4	0
NR-17	0	0	0
NR-18	1,248	7.5	254
NR-19	487	5	215
NR-20	404	3	255
NR-21	0	0	0
NR-22	0	0	0
NR-23	0	0	16
Total	7,008	38	1,936

[a] fractions represent dairy farms that are within multiple watersheds

Beef cattle in the watershed included cow/calf and feeder operations. There were no permitted beef CAFOs in the watershed. The beef cattle population (1,936) in the watershed was estimated based on consultation with local extension agents for the area. The total number of beef cows varied throughout the year due to the presence or absence of calves and their weights relative to the adult cattle.

Beef and dairy cattle spend varying amounts of time in confinement, loafing lots, streams, and pasture depending on the time of year and type of cattle (e.g., milk cow versus heifer). Accordingly, the proportion of fecal coliform deposited in any given land area varies throughout the year. Based on discussions with NRCS, VADCR, VCE, and local producers, the following assumptions and procedures were used to estimate the distribution of cattle (and thus their manure) among different land use types and in the stream.

a) Cows are confined according to the schedule given in Table 4.5.

b) When dairy and beef cattle are not confined, they are on pasture.

c) Beef cattle on pastures that are contiguous to unfenced streams have stream access. This number was obtained through analysis of GIS land use and stream information. Stream access reported by dairy farmers during data collection was used for the dairy cows.

d) Cows with stream access spend varying amounts of time in the stream during different seasons (Table 4.5). Cows spend more time in the stream during the three summer months to protect their hooves from hornflies, among other reasons.

e) Thirty percent of cows in and around streams directly deposit fecal coliform into the stream. The remaining 70% of the manure is deposited on pastures.

Table 4.5. Time spent by cattle in confinement and in the stream.

Month	Time spent in confinement (%)[a]		Time spent in the stream (hours/day)[b]
	Milk cows	Dry cows, heifers, and beef cattle	
January	40-80%	40%	0.50
February	40-80%	40%	0.50
March	20-80%	0-25%	0.75
April	12.5-80%	0-25%	1.00
May	12.5-80%	0-25%	1.50
June	12.5-80%	0-25%	3.50
July	12.5-80%	0-25%	3.50
August	12.5-80%	0-25%	3.50
September	12.5-80%	0-25%	1.50
October	12.5-80%	0-25%	1.00
November	20-80%	0-25%	0.75
December	40-80%	40%	0.50

[a] The range of numbers in these columns indicate the range of confinement for each month reported by the dairy farmers

[b] Time spent in and around the stream by cows that have stream access.

A sample calculation for determining the distribution of cattle to different land use types and to the stream in sub-watershed NR-03 is shown in Appendix B. The resulting numbers of cattle in each land use type as well as in the stream for all sub-watersheds are given in Table 4.6 for dairy cattle and in Table 4.7 for beef cattle.

Table 4.6. Distribution of the dairy cattle[a] population.

Month	Confined	Pasture	Streams[b]
January	3894.92	3110.29	1.89
February	3894.92	3110.29	1.89
March	1988.10	5014.93	4.47
April	1775.59	5225.69	6.22
May	1775.59	5222.58	9.33
June	1775.59	5210.14	21.77
July	1775.59	5210.14	21.77
August	1775.59	5210.14	21.77
September	1775.59	5222.58	9.33
October	1775.59	5225.69	6.22
November	1988.10	5014.93	4.47
December	3894.92	3110.29	1.89

[a] Includes milk cows, dry cows, and heifers.

[b] Number of dairy cattle defecating in stream.

Table 4.7. Distribution of the beef cattle population.

Months	Confined	Pasture	Stream[a]
January	832.48	1248.37	0.35
February	907.98	1361.59	0.38
March	0.00	2307.71	0.97
April	0.00	2346.08	1.32
May	0.00	2384.11	2.01
June	0.00	2420.08	4.76
July	0.00	2458.72	4.84
August	0.00	2497.37	4.91
September	0.00	2538.86	2.14
October	0.00	1934.91	1.09
November	0.00	1983.57	0.83
December	813.12	1219.34	0.34

[a] Number of beef cattle defecating in stream.

4.2.2. Direct Manure Deposition in Streams

Direct manure loading to streams is due to both dairy (Table 4.6) and beef cattle (Table 4.7) defecating in the stream. Manure loading increases during the warmer months when cattle spend more time in water compared to the cooler months. The potential average annual manure loading directly deposited by cattle in the stream for the entire watershed is 324,945 lb. This number will vary year to year according to the amount of time that the streams in the watershed are flowing. The associated average daily fecal coliform loading to the stream is 1.9×10^{11} cfu/day; this number will also vary year to year according to the amount of time the streams in the watershed are flowing. Part of the fecal coliform deposited in the stream stays suspended while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that suspended fecal coliform bacteria are the primary form transported with the flow. Sediment-bound fecal coliform bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. Die-off of fecal coliform in the stream depends on sunlight, predation, turbidity, and other environmental factors.

4.2.3. Direct Manure Deposition on Pastures

Dairy (Table 4.6) and beef (Table 4.7) cattle that graze on pastures but do not deposit in streams contribute the majority of fecal coliform loading on pastures. Manure loading on pasture was estimated by multiplying the total number of each type of cattle (milk cow, dry cow, heifer, and beef) on pasture by the amount of manure produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Because the confinement schedule of the cattle changes with season, manure and fecal coliform loading on pasture also change with season.

Pasture has average annual cattle manure loadings of 5,970 lb/ac-year. The associated fecal coliform loadings from cattle to pasture on a daily basis, averaged over the year, are 4.1×10^9 cfu/ac-day. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

4.2.4. Land Application of Liquid Dairy Manure

A typical milk cow weighs 1,400 lb and produces 17 gallons of liquid manure daily (ASAE, 1998). Based on the monthly confinement schedule (Table 4.5) and the number of milk cows (Table 4.6), annual liquid dairy manure production in the watershed is 19.7 million gallons. Based on the per capita fecal coliform production of milk cows, the fecal coliform concentration in fresh liquid dairy manure is 1.18×10^9 cfu/gal. Liquid dairy manure receives priority over other manure types (poultry litter and solid cattle manure) when applied to land. Liquid dairy manure application rates are 10,000 and 3,900 gal/ac-year to cropland and pasture land use categories, respectively, with cropland receiving priority in application. Based on availability of land and liquid dairy manure, as well as the assumptions regarding application rates and priority of application, it was estimated that liquid dairy manure was applied to 1,589 acres (31.4%) of cropland and 469 acres (1.6%) of pasture.

For modeling purposes, a ten-year rotation with four years of corn-rye and six years of rotational hay was assumed. It was assumed that 50% of the corn acreage was under no-till cultivation. Liquid manure is applied to cropland during February through May (prior to planting) and in October-November (after the crops are harvested). For spring application to cropland, liquid manure is applied on the soil surface to rotational hay and no-till corn, and is incorporated into the soil for corn in conventional tillage. In fall, liquid manure is incorporated into the soil for cropland under rye, and surface-applied to cropland under rotational hay. In all months except December and January, liquid manure can be surface-applied to pasture. It was assumed that only 10% of the subsurface-applied fecal coliform was available for removal in surface runoff. The application schedule for manure is given in Table 4.8. Dry cows and heifers were assumed to produce only solid manure.

Table 4.8. Schedule of cattle and poultry waste application in the North River TMDL watershed.

Month	Liquid manure applied (%)[a]		Solid manure or poultry litter applied (%)[a]	
	Crops	Pasture	Crops	Pasture
January	0	0	0	0
February	7.1	5	6.7	5
March	35.7	25	33.3	25
April	28.6	20	26.7	20
May	7.1	5	6.7	5
June	0	10	0	5
July	0	0	0	5
August	0	5	0	5
September	0	15	0	10
October	7.1	5	13.3	10
November	14.3	10	13.3	10
December	0	0	0	0

[a] As percent of annual load applied to each land use type.

4.2.5. Land Application of Solid Manure

Solid manure produced by dry cows, heifers, and beef cattle during confinement is collected for land application. It was assumed that milk cows produce only liquid manure while in confinement. The number of cattle, their typical weights, amounts of solid manure produced, and fecal coliform concentration in fresh manure are given in Table 4.9. Solid Manure is last on the priority list for application to land (it falls behind liquid manure and poultry litter). The amount of solid manure produced in each sub-watershed was estimated based on the populations of dry cows, heifers, and beef cattle in the sub-watershed (Table 4.1) and their confinement schedules (Table 4.5). Solid manure from dry cows, heifers, and beef cattle contained different fecal coliform concentrations (cfu/lb) (Table 4.9).

Table 4.9. Estimated population of dry cows, heifers, and beef cattle, typical weights, per capita solid manure production, and fecal coliform concentration in fresh solid manure.

Type of cattle	Population	Typical weight (lb)	Solid manure produced (lb/animal-day)	Fecal coliform concentration in fresh manure ($\times 10^6$ cfu/lb)
Dry cow	571	1,400[a]	115.0[b]	176[c]
Heifer	2526	640[d]	40.7[a]	226[c]
Beef	1,936	1,000	60.0[b]	333[c]

[a] Source: ASAE (1998)
[b] Source: MWPS (1993)
[c] Based on per capita fecal coliform production per day (Table 4.1) and manure production
[d] Based on weighted average weight assuming that 57% of the animals are older than 10 months (900 lb ea.), 28% are 1.5-10 months (400 lb ea.) and the remainder are less than 1.5 months (110 lb ea.) (MWPS, 1993).

Solid manure is applied at the rate of 7 tons/ac-year to both cropland and pasture, with priority given to cropland. As in the case of liquid manure, solid manure is only applied to cropland during February through May, October, and November. Solid manure can be applied to pasture during the whole year, except December and January. The incorporation properties of the application of solid manure to cropland or pasture are assumed to be identical to the incorporation properties of the application of liquid dairy manure. The application schedule for solid manure is given in Table 4.8. Based on availability of land and solid manure, as well as the assumptions regarding application rates and priority of application, it was estimated that solid cattle manure was applied to 5.74 acres (0.11%) of cropland and 495.5 acres (1.6%) of pasture.

4.3. Poultry

The poultry population (Table 4.1) was estimated based on the permitted confined feeding operations (CAFOs) located within the watershed. A complete listing of poultry CAFOs can be found in Table J.1 in Appendix J. Poultry litter production was estimated from the poultry population after accounting for the time when the houses are not occupied.

Because poultry is raised entirely in confinement, all litter produced is collected and stored prior to land application. The estimated production rate of poultry litter in the North River TMDL watershed is 7.3×10^7 lb/year; this corresponds to a fecal coliform application rate of 7.8×10^{15} cfu/year. The fecal coliform bacteria produced are subject to die-off in storage and losses due to incorporation prior to being subject to transport via runoff. Poultry litter was applied at the rate of 3 tons/ac-year first to cropland and then to pastures. Poultry litter receives priority after all liquid manure has been applied (i.e., it is applied before solid cattle manure is considered). The incorporation properties of poultry litter application to cropland and pastures are assumed to be identical to the incorporation properties of cattle manure application. The application schedule of poultry litter is given in Table 4.8. As with liquid and solid manures, poultry litter is not applied to cropland during June through September. Based on availability of land and poultry litter, as well as the assumptions regarding application rates and priority of application, it was estimated that poultry litter was applied to 3,451 acres (68%) of cropland and 8,670 acres (29%) of pasture.

4.4. Sheep and Goats

The sheep and goat population (Table 4.1) was estimated based on population densities in the USDA National Agricultural Statistics Service (NASS) for Rockingham and Augusta Counties, Virginia. The sheep herd was composed of lambs and ewes. The lamb population was expressed in equivalent sheep numbers, and reflected two lambs per ewe. The equivalent sheep population calculated for lambs was based on the assumption that the average weight of a lamb is half of the weight of a sheep. The total number of sheep for the North River TMDL watershed was the sum of the number of ewes (739), the equivalent number of lambs (739), and the equivalent number of goats (301) for a total of 1,779 animals. The sheep and goats were kept on pasture at all times. Sheep and goats are not usually confined and tend not to wade or defecate in the streams. Therefore, the fecal coliform produced by sheep and goats was deposited directly on pasture.

Pasture in the North River TMDL watershed has average annual sheep and goat manure loadings of 51.7 lb/ac-year. Fecal coliform loadings to the pasture in the North River TMDL watershed from sheep and goats on a daily basis averaged over the year are 7.08×10^{8} cfu/ac-day.

4.5. Horses

Horse total populations for the North River TMDL watershed were obtained based on population densities in the USDA National Agricultural Statistics Service (NASS) for Rockingham and Augusta Counties, Virginia. The total horse population was estimated to be 419 and was deemed satisfactory by local stakeholders during the Steering Committee meetings. The distribution of horse population among the sub-watersheds agreed upon by the Local Steering Committee is listed in Table 4.10. The fecal coliform produced by horses is contributed to pasture areas. Fecal coliform loadings from horses on a daily basis averaged over the year and over pasture areas in the North River TMDL watershed are 5.8×10^{6} cfu/ac-day.

Table 4.10. Horse Populations in North River Sub-Watersheds.

Sub-watershed	Horse Population
NR-01	3
NR-02	3
NR-03	50
NR-04	15
NR-05	42
NR-06	43
NR-07	38
NR-08	1
NR-09	1
NR-10	33
NR-11	6
NR-12	8
NR-13	20
NR-14	7
NR-15	2
NR-17	7
NR-18	56
NR-19	38
NR-20	42
NR-21	1
NR-22	0
NR-23	3
Total	419

4.6. Wildlife

Wildlife fecal coliform contributions can come from excretion of waste on land and from excretion directly into streams. Information provided by VADGIF, professional trappers, and watershed residents were used to estimate wildlife populations. Wildlife species that were found in quantifiable numbers in the watershed included deer, raccoon, muskrat, beaver, wild turkey, goose, and wood duck. Population numbers for each species and fecal coliform amounts were determined (Table 4.1) along with preferred habitat and habitat area (Table 4.11).

Professional judgment was used in estimating the percent of each wildlife species depositing directly into streams, considering the habitat area each occupied (Table 4.11). Fecal loading from wildlife was estimated for each sub-watershed. The wildlife populations were distributed among the sub-watersheds based on the area of appropriate habitat in each sub-watershed. For example, the deer population was evenly distributed across the watershed, whereas muskrat and raccoons had variable population densities based on land use and proximity to a water source. Therefore, a sub-watershed with more stream length and impoundments and more area in crop land use would have more muskrats than a sub-watershed with shorter stream length and fewer impoundments, and less area in crop land use. Distribution of wildlife among sub-watersheds is given in Table 4.12.

Table 4.11. Wildlife habitat and densities description and percent direct fecal deposition in streams.

Wildlife type	Habitat	Population Density (animal / mi² -habitat)	Direct fecal deposition in streams (%)
Deer	Entire Watershed	30	1%
Raccoon	low density on forests not in high density area; high density on forest within 600 ft of a permanent water source or 0.5 mile of cropland	Low density: 10 High density: 30	10%
Muskrat	16/mile of ditch or medium sized stream intersecting cropland; 8/mile of ditch or medium sized stream intersecting pasture; 10/mile of pond or lake edge; 50/mile of slow-moving river edge	-see habitat column-	25%
Beaver	300 ft buffer streams and impoundments in forest and pasture	9.6	50%
Geese	300 ft buffer around main streams	50 – off season 70 – peak season	25%
Wood Duck	300 ft buffer around main streams	40 - off season 60 – peak season	25%
Wild Turkey	Entire Watershed except urban and farmstead	6.4	1%

Table 4.12. Distribution of wildlife among sub-watersheds.

Sub-watershed	Deer	Raccoon	Muskrat	Beaver	Geese		Wood Duck		Wild Turkey
					Off-Peak	Peak	Off-Peak	Peak	
NR-01	16	5	94	1	9	9	9	9	3
NR-02	12	3	68	1	9	19	9	9	2
NR-03	206	26	12	2	84	112	75	103	43
NR-04	82	24	292	3	9	19	9	9	17
NR-05	213	36	13	3	149	205	121	177	44
NR-06	222	57	2	1	75	93	56	84	44
NR-07	206	66	362	6	65	84	56	75	43
NR-08	6	2	42	1	9	9	9	9	1
NR-09	16	8	141	1	9	9	9	9	3
NR-10	171	43	87	1	9	9	9	9	36
NR-11	37	8	224	3	9	9	9	9	7
NR-12	77	27	237	3	9	9	9	9	11
NR-13	107	19	42	2	12	17	10	14	22
NR-14	35	3	3	1	4	5	3	4	7
NR-15	12	3	7	1	7	10	6	9	2
NR-17	73	40	7	4	23	32	18	27	15
NR-18	286	57	27	5	29	40	23	34	60
NR-19	380	131	6	1	5	7	4	6	81
NR-20	509	258	39	11	63	89	51	76	107
NR-21	923	463	12	22	113	158	90	136	195
NR-22	1,952	954	36	45	36	51	29	43	415
NR-23	14	3	4	1	6	9	5	8	3
Total	5,555	2,236	1,757	119	743	1,004	619	868	1,161

4.7. Summary: Contribution from All Sources

Based on the inventory of sources discussed in this chapter, a summary of the contribution by the different nonpoint sources to direct annual fecal coliform loading to the streams is given in Table 4.13. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 4.13.

From Table 4.13, it is clear that nonpoint source loadings to the land surface are nearly 450 times larger than direct nonpoint loadings to the streams, with pastures receiving about 92% of the total fecal coliform load. It could be prematurely assumed that most of the fecal coliform loading in streams originates from upland sources, primarily from pastures. However, other factors, such as precipitation amount and pattern, manure application activities (time and method), type of waste (solid versus liquid manure), and proximity to streams also impact the amount of fecal coliform from upland areas that reaches the streams. The HSPF model considers these factors when estimating fecal coliform loads to the receiving waters, as described in Chapter 5.

Table 4.13. Annual fecal coliform loadings to the stream and the various land use categories in the North River TMDL watershed.

Source	Fecal coliform loading ($x10^{12}$ cfu/year)	Percent of total loading
Direct loading to streams		
Cattle in stream	70.8	<0.1%
Wildlife in stream	59.6	<0.1%
Straight pipes	6.08	<0.1%
Loading to land surfaces		
Cropland	2,340	3.7%
Pasture	58,730	92.0%
Residential[a]	1,651	2.6%
Forest	812	1.3%
Total	63,670	

[a] Includes loads received from both High and Low Density Residential due to failed septic systems and pets.

CHAPTER 5: MODELING PROCESS FOR BACTERIA TMDL DEVELOPMENT

A key component in developing a TMDL is establishing the relationship between pollutant loadings (both point and nonpoint) and in-stream water quality conditions. Once this relationship is developed, management options for reducing pollutant loadings to streams can be assessed. In developing a TMDL, it is critical to understand the processes that affect the fate and transport of the pollutants and cause the impairment of the waterbody of concern. Pollutant transport to water bodies is evaluated using a variety of tools, including monitoring, geographic information systems (GIS), and computer simulation models. In this chapter, the modeling process, input data requirements, and model calibration procedure and results are discussed.

5.1. Model Description

The TMDL development requires the use of a watershed-based model that integrates both point and nonpoint sources and simulates in-stream water quality processes. The Hydrologic Simulation Program – FORTRAN (HSPF) version 12 (Bicknell *et al.*, 2001; Duda *et al.*, 2001) was used to model fecal coliform transport and fate in the North River watershed. The ArcGIS 9.1 GIS program was used to display and analyze landscape information for the development of input for HSPF.

The HSPF model simulates nonpoint source runoff and pollutant loadings, performs flow routing through streams, and simulates in-stream water quality processes. HSPF estimates runoff from both pervious and impervious parts of the watershed and stream flow in the channel network. The sub-module PWATER within the module PERLND simulates runoff, and hence, estimates the water budget on pervious areas (e.g., agricultural land). Runoff from impervious areas is modeled using the IWATER sub-module within the IMPLND module. The simulation of flow through the stream network is performed using the sub-modules HYDR and ADCALC within the module RCHRES. While HYDR routes the water through the stream network, ADCALC calculates variables used for simulating convective transport of the pollutant in the stream. Fate of fecal coliform on pervious and impervious land segments is simulated using the PQUAL (PERLND module) and IQUAL (IMPLND module) sub-modules, respectively. Fate of fecal coliform in stream water is simulated using the general constituent pollutant (GQUAL) sub-module within RCHRES module. Fecal coliform bacteria are simulated as dissolved pollutants in the GQUAL sub-module.

5.2. Input Data Requirements

The HSPF model requires a wide variety of input data to describe hydrology, water quality, and land use characteristics of the watershed. The different types and sources of input data used to develop the TMDLs for the North River watershed are discussed below.

5.2.1. Climatological Data

Hourly precipitation data were obtained from the Dale Enterprise weather station in Rockingham County, located inside the northern part of the watershed. Because hourly data for other meteorological parameters were not available at Dale Enterprise, daily data from Lynchburg Airport (Virginia) and Elkins Airport (West Virginia) were used to complete the meteorological data set required for running HSPF. Detailed descriptions of the weather data and the procedure for converting the raw data into the required data set are presented in Appendix D.

5.2.2. Model Parameters

The hydrology parameters required by HSPF were defined for every land use category for each sub-watershed. Required hydrology parameters are listed in the HSPF Version 12 User's Manual (Bicknell *et al.*, 2001). Initial estimates for required hydrology parameters were generated based on guidance in BASINS Technical Note 6 (USEPA, 2000a); these parameters were refined during calibration. Each reach requires a function table (FTABLE) to describe the relationship between water depth, surface area, volume, and discharge (Bicknell *et al.*, 2001). The FTABLE parameters were estimated using a digital elevation model (DEM) of the area in addition to relationships developed by the NRCS that relate stream characteristics to drainage area. Information on the calculated stream geometry for each sub-watershed is presented in Table 5.1 for the bankfull condition.

Required water quality parameters are also given in the HSPF User's Manual (Bicknell *et al.*, 2001). Initial estimates for bacteria loading parameters were based on estimates of bacteria production in the watershed; estimates of die-off rates and subsurface bacteria concentrations were based on values commonly used in previous TMDLs.

Table 5.1. Stream Characteristics of North River.

Sub-watershed[a]	Stream length (mile)	Average bankfull width (ft)	Average bankfull channel depth (ft)	Slope (ft/ft)
NR-01	0.95	101	7.69	0.0013
NR-02	0.66	101	7.69	0.00085
NR-03	1.62	28.2	2.78	0.0042
NR-04	2.90	99.1	7.60	0.00087
NR-05	2.96	98.6	7.57	0.0021
NR-06	1.16	97.2	7.48	0.0012
NR-07	4.82	95.7	7.39	0.0014
NR-08	0.42	94.3	7.30	0.0012
NR-09	1.48	94.2	7.30	0.0016
NR-10	0.94	94.1	7.29	0.00069
NR-11	2.13	92.9	7.22	0.0024
NR-12	3.23	92.6	7.20	0.00095
NR-13	2.69	92.0	7.17	0.0028
NR-14	0.67	91.2	7.12	0.0028
NR-15	1.57	59.4	5.05	0.00062
NR-17	4.34	51.1	4.47	0.011
NR-18	3.23	78.7	6.32	0.0036
NR-19	0.93	35.6	3.35	0.0036
NR-20	6.60	71.8	5.87	0.007
NR-21	8.68	49.6	4.37	0.026
NR-22	18.1	65.8	5.48	0.023
NR-23	1.33	71.9	5.88	0.0046
NR-30	6.03	38.0	3.53	0.0078
NR-31	6.27	30.3	2.95	0.010
NR-32	2.83	56.8	4.87	0.0023
NR-33	10.6	41.5	3.79	0.0043
NR-34	7.62	44.2	3.99	0.0027
NR-35	2.21	82.8	6.59	0.0061
NR-36	10.4	50.0	4.40	0.0028
NR-37	4.12	27.4	2.72	0.0078
NR-38	7.57	70.9	5.82	0.0090
NR-39	11.8	68.7	5.67	0.014
NR-40	5.32	38.7	3.58	0.0086
NR-41	9.06	38.6	3.58	0.0043
NR-42	9.97	41.1	3.77	0.0054
NR-43	5.57	44.5	4.00	0.0054
NR-44	17.5	127	9.28	0.00062
NR-45	31.5	79.5	6.38	0.0053
NR-46	22.7	106	8.02	0.0018
NR-47	11.3	47.2	4.20	0.0060
NR-48	4.64	88.5	6.95	0.0015
NR-49	6.69	84.7	6.71	0.0028
NR-50	16.0	64.7	5.40	0.0041
NR-51	0.35	80.4	6.43	0.022

5.3. Accounting for Pollutant Sources

5.3.1. Overview

There were 2 VPDES facilities permitted to discharge bacteria into North River: Weyers Cave STP (VA0022349) and North River WWTF (VA0060640). Additionally, 16 general permit dischargers were located in North River (Table 4.2). The fecal coliform concentration in the discharges from these facilities cannot exceed 200 cfu/100 mL. During calibration, reported concentrations from these facilities were incorporated into the model; during allocation, concentrations from these facilities were set at their permitted limits. Other permitted facilities existing in the areas covered by a previously developed TMDL are summarized in previous TMDL reports; their flows and bacteria concentrations were considered in the modeling of the whole North River watershed.

In addition to the point source permits, an MS4 permit exists for the town of Bridgewater (VAR040054). While the MS4 permit is regulated similarly to point source discharges, water quality discharging from the MS4 is nearly exclusively dictated by nonpoint source runoff (along with an unknown, but presumed small, amount of illicit connections). Fecal coliform loads modeled from impervious areas within the MS4 area are included in the wasteload allocation (WLA) component of the TMDL, in compliance with 40 CFR §130.2(h). Fecal coliform loads related to stormwater runoff from areas covered by the MS4 permit were modeled in HSPF as contributions from impervious land use categories.

Bacteria loads that are directly deposited by cattle and wildlife in streams were treated as direct nonpoint sources in the model. Bacteria that were land-applied or deposited on land were treated as nonpoint source loadings; all or part of that load may be transported to the stream as a result of surface runoff during rainfall events. Direct nonpoint source loading was applied to the stream reach in each sub-watershed as appropriate. The point sources permitted to discharge bacteria in the watershed were incorporated into the simulations at the stream locations designated in the permit.

The nonpoint source loading was applied in the form of fecal coliform counts to each land use category in a sub-watershed. Fecal coliform die-off was simulated while manure was being stored, while it was on the land, and while it was transported in streams. Both direct nonpoint and nonpoint source loadings were varied by month to account for seasonal differences such as cattle and wildlife access to streams.

We developed a spreadsheet program internally (Zeckoski et al., 2005) and used it to generate the nonpoint source fecal coliform inputs to the HSPF model. This spreadsheet program takes inputs of animal numbers, land use, and management practices by sub-watershed and outputs hourly direct deposition to streams and monthly loads to each land use type. We customized the program to allow direct deposition in the stream by dairy cows, ducks, and geese to occur only during daylight hours. The spreadsheet program calculates the manure produced in confinement by each animal type (dairy cows, beef cattle, and poultry) and distributes this manure to available lands (crops and pasture) within each sub-watershed. If a sub-watershed does not have sufficient land to apply all the manure its animals generate, the excess manure is distributed equally to other sub-watersheds that have land that has not yet received manure.

5.3.2. Modeling fecal coliform die-off

Fecal coliform die-off was modeled using first order die-off of the form:

$$C_t = C_0 10^{-Kt} \qquad [5.1]$$

where: C_t = concentration or load at time t,

C_0 = starting concentration or load,

K = decay rate (day^{-1}),

and t = time in days.

A review of literature provided estimates of decay rates that could be applied to waste storage and handling in the North River TMDL watershed (Table 5.2).

Table 5.2. First order decay rates for different animal waste storage as affected by storage/application conditions and their sources.

Waste type	Storage/application	Decay rate (day^{-1})	Reference
Dairy manure	Pile (not covered)	0.066	Crane and Moore (1986)
	Pile (covered)	0.028	
Beef manure	Anaerobic lagoon	0.375	Crane and Moore (1986)
Poultry litter	Soil surface	0.035	Giddens *et al.* (1973)
		0.342	Crane *et al.* (1980)

Based on the values cited in the literature, the following decay rates were used in simulating fecal coliform die-off in stored waste.

- Liquid dairy manure: Because the decay rate for liquid dairy manure storage could not be found in the literature, the decay rate for beef manure in anaerobic lagoons (0.375 day^{-1}) was used.
- Solid cattle manure: Based on the range of decay rates (0.028-0.066 day^{-1}) reported for solid dairy manure, a decay rate of 0.05 day^{-1} was used, assuming that a majority of manure piles are not covered.
- Poultry waste in pile/house: Because no decay rates were found for poultry waste in storage, a decay rate of 0.035 day^{-1} was used based on the lower decay rate reported for poultry litter applied to the soil surface. The lower value was used instead of the higher value of 0.342 day^{-1} (Table 5.2) because fecal coliform die-off in storage was assumed to be lower, given the absence of UV radiation and predation by soil microbes.

The procedure for calculating fecal coliform counts in waste at the time of land application is included in Appendix C. Depending on the duration of storage, type of storage, type of manure, and die-off factor, the fraction of fecal coliform surviving in the manure at the end of storage is calculated. While calculating survival fraction at the end of the storage period, the daily addition of manure and coliform die-off of each fresh manure addition is considered to arrive at an effective survival fraction over the entire storage period. The amount of fecal coliform available for application to land per year is estimated by multiplying the survival fraction with total fecal coliform produced per year (in as-excreted manure). Monthly fecal coliform application to land is estimated by multiplying the amount of fecal coliform available for application to land per year by the fraction of manure applied to land during that month. A base-10 decay rate of 0.05 day^{-1} was assumed for fecal coliform on the land surface. The decay rate of 0.05 day^{-1} is represented in HSPF by specifying a maximum surface buildup of nine times the daily loading rate. An in-stream decay rate of 1.15 day^{-1} was used.

5.3.3. Modeling Nonpoint Sources

For modeling purposes, nonpoint fecal coliform loads were those that were deposited or applied to land and, hence, required surface runoff events for transport to streams. Fecal coliform loading by land use for all sources in each sub-watershed is presented in Chapter 4. The existing condition fecal coliform loads are based on best estimates of existing wildlife, livestock, and human populations and fecal coliform production rates. Fecal coliform in stored waste was adjusted for die-off prior to the time of land application when calculating loadings to cropland and pasture. For a given period of storage, the total amount of fecal coliform present in the stored manure was adjusted for die-off on a daily basis. Fecal coliform loadings to each sub-watershed in the North River TMDL watershed are presented in Appendix F. The sources of fecal coliform to different land use categories and how the model handled them are briefly discussed below.

1. Cropland: Liquid dairy manure and solid manure are applied to cropland as described in Chapter 4. Fecal coliform loadings to cropland were adjusted to account for die-off during storage and partial incorporation during land application. Wildlife contributions were also added to the cropland areas. For modeling, the monthly fecal coliform loading assigned to cropland was distributed over the entire cropland acreage within a sub-watershed. Thus, loading rate varied by month and sub-watershed.

2. Pasture: In addition to direct deposition from livestock and wildlife, pastures receive applications of liquid dairy manure and solid manure as

described in Chapter 4. Applied fecal coliform loading to pasture was reduced to account for die-off during storage. For modeling, the monthly fecal coliform loading assigned to pasture was distributed over the entire pasture acreage within a sub-watershed.

3. Low Density Residential: Fecal coliform loading on rural residential land use came from failing septic systems and waste from pets. In the model simulations, fecal coliform loads produced by failing septic systems and pets in a sub-watershed were combined and assumed to be uniformly applied to the low density residential pervious land use areas. Impervious areas (Table 3.1) received constant loads of 1.0×10^7 cfu/acre/day.
4. High-Density Residential: Fecal coliform loading to the high density residential land use came from pets in these areas; the impervious load was assumed to be a constant 1.0×10^7 cfu/acre/day (USEPA, 2000b).
5. Forest: Wildlife not defecating in streams, cropland, or pastures provided fecal coliform loading to the forested land use. Fecal coliform from wildlife in forests was applied uniformly over the forest areas in each sub-watershed.

5.3.4. Modeling Direct Nonpoint Sources

Fecal coliform loads from direct nonpoint sources included cattle in streams, wildlife in streams, and direct loading to streams from straight pipes from residences. Loads from direct nonpoint sources in each sub-watershed are described in detail in Chapter 4. Contributions of fecal coliform from interflow and groundwater were modeled as having a constant concentration of 30 cfu/100mL for interflow and 20 cfu/100mL for groundwater for most land uses. In low density residential areas, these concentrations were increased to 60 cfu/100 mL and 40 cfu/100 mL during the water quality calibration. This was done to represent the increased loading to interflow and groundwater in residential areas due to septic systems failing down into the karst system in North River.

5.4. Model Calibration and Validation

Model calibration is the process of selecting model parameters that provide an accurate representation of the watershed. In this section, the procedures followed for calibrating the hydrology and water quality components of the Hydrological Simulation Program-FORTRAN (HSPF) model are discussed.

5.4.1. Hydrology

The HSPEXP decision support system developed by USGS was used to assist in calibrating the hydrologic portion of HSPF for North River. The default HSPEXP criteria for evaluating the accuracy of the flow simulation were used in the calibration for North River. These criteria are listed in Table 5.3. After calibration, all criteria listed in Table 5.3 were met.

Table 5.3. Default criteria for HSPEXP.

Variable	Percent Error
Total Volume	10%
50 % Lowest Flows	10%
10 % Highest Flows	15%
Storm Peaks	15%
Seasonal Volume Error	10%
Summer Storm Volume Error	15%

The hydrologic calibration period was September 1, 1985 to August 31, 1990. The hydrologic validation period was from September 1, 1990 to December 31, 1994. The output from the HSPF model for both calibration and validation was daily average flow in cubic feet per second (cfs). Calibration parameters were adjusted within the recommended range (USEPA, 2000a).

The simulated flow for both the calibration and validation matched the observed flow well, as shown in Figure 5.1 and Figure 5.2. The agreement with observed flows is further illustrated in Figure 5.3 and Figure 5.4 for a representative year and Figure 5.5 and Figure 5.6 for a representative storm. The agreement between the simulated and observed time series can be further seen through the comparison of their cumulative frequency curves (Figures 7 and 8).

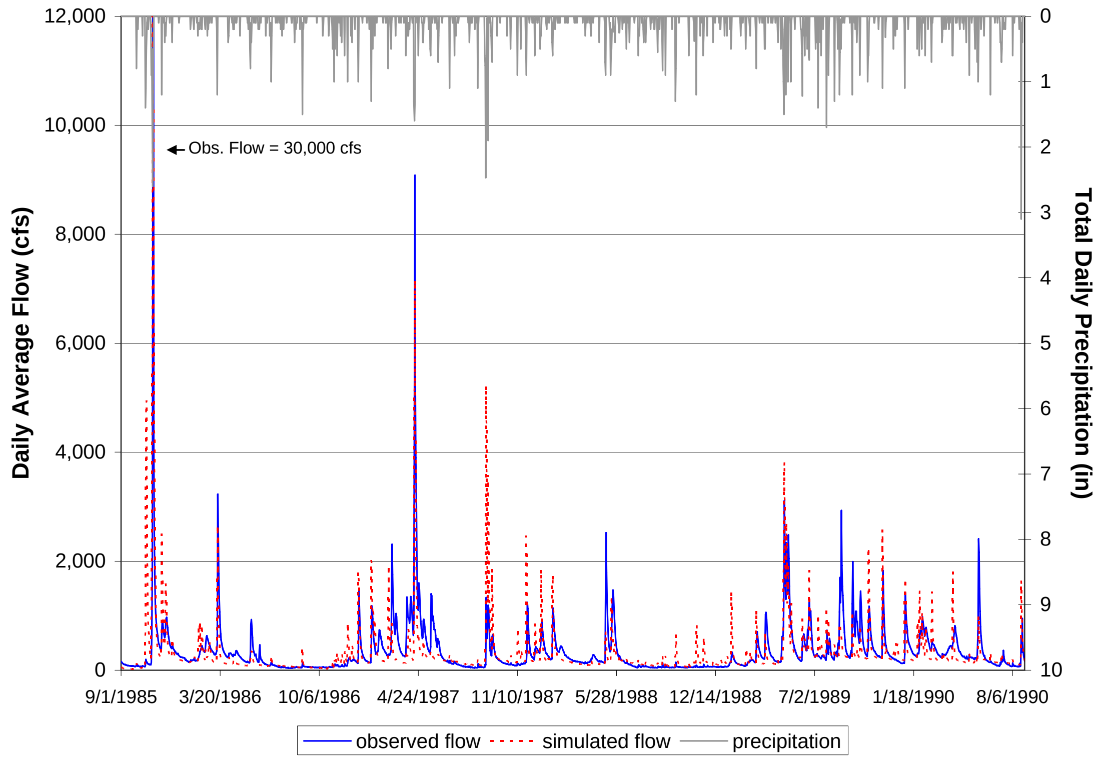

Figure 5.1. Observed and simulated flows and precipitation for North River for the calibration period.

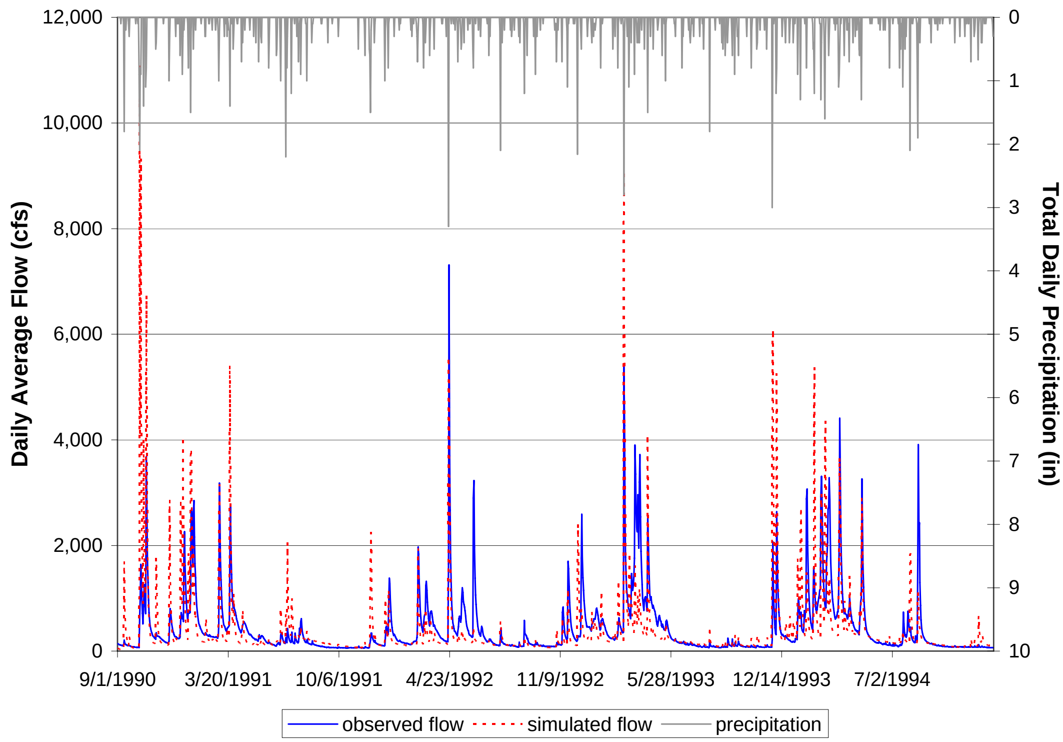

Figure 5.2. Observed and simulated flows and precipitation for North River during the validation period.

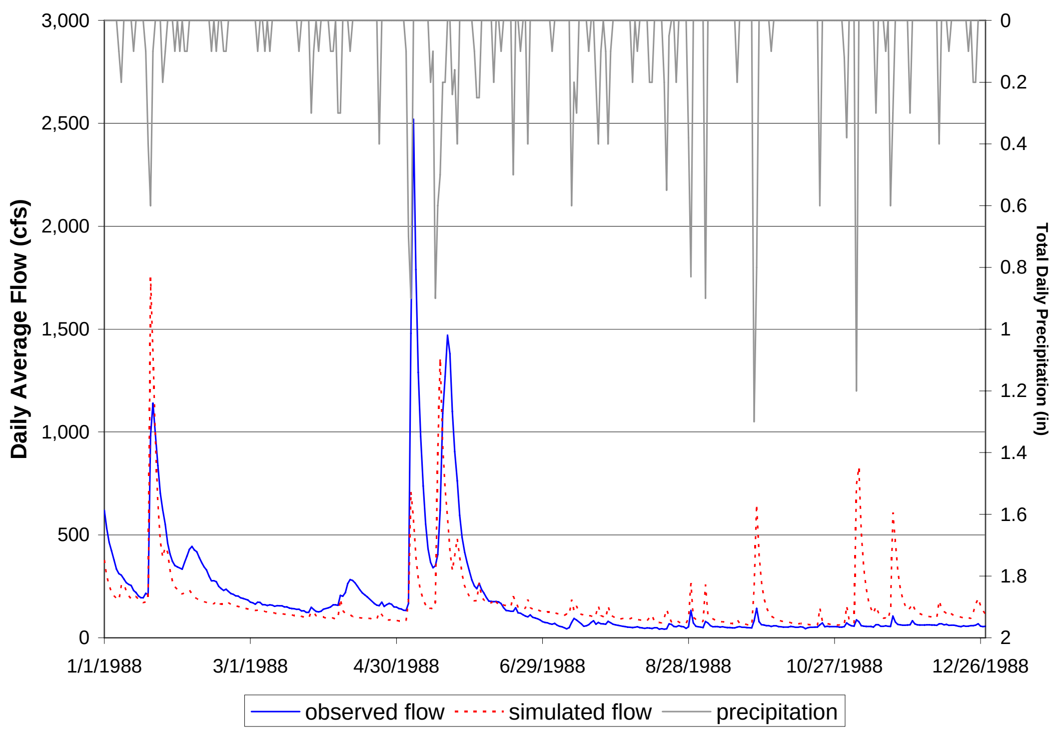

Figure 5.3. Observed and simulated flows and precipitation for North River for a representative year in the calibration period.

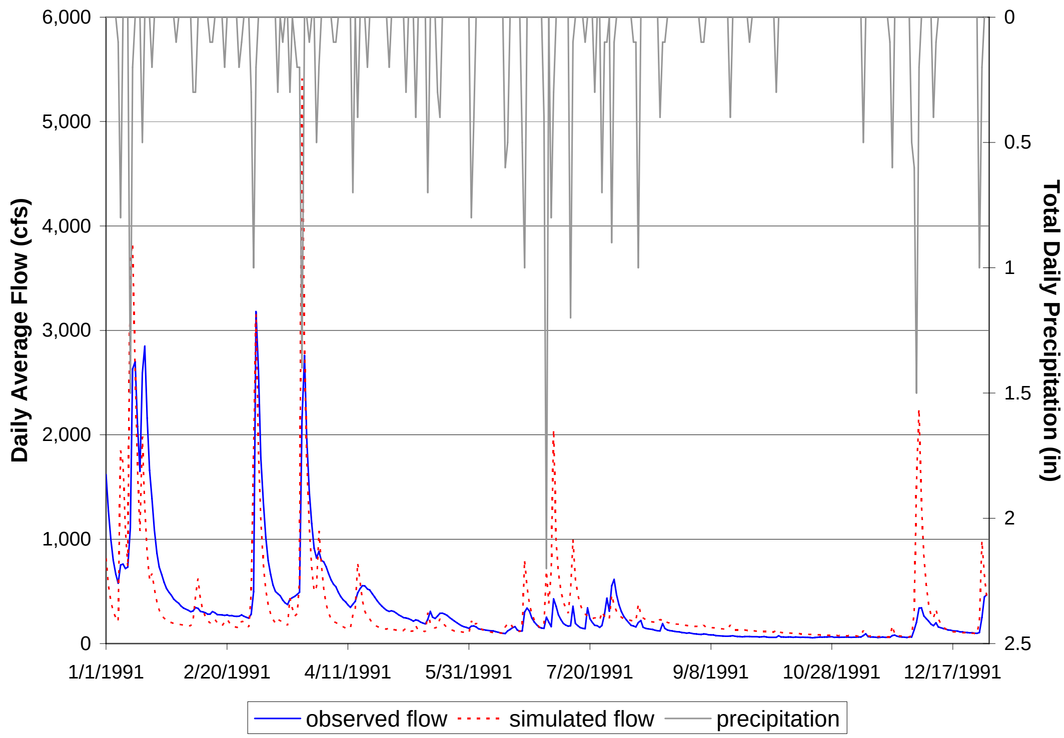

Figure 5.4. Observed and simulated flows and precipitation for North River during a representative year in the validation period.

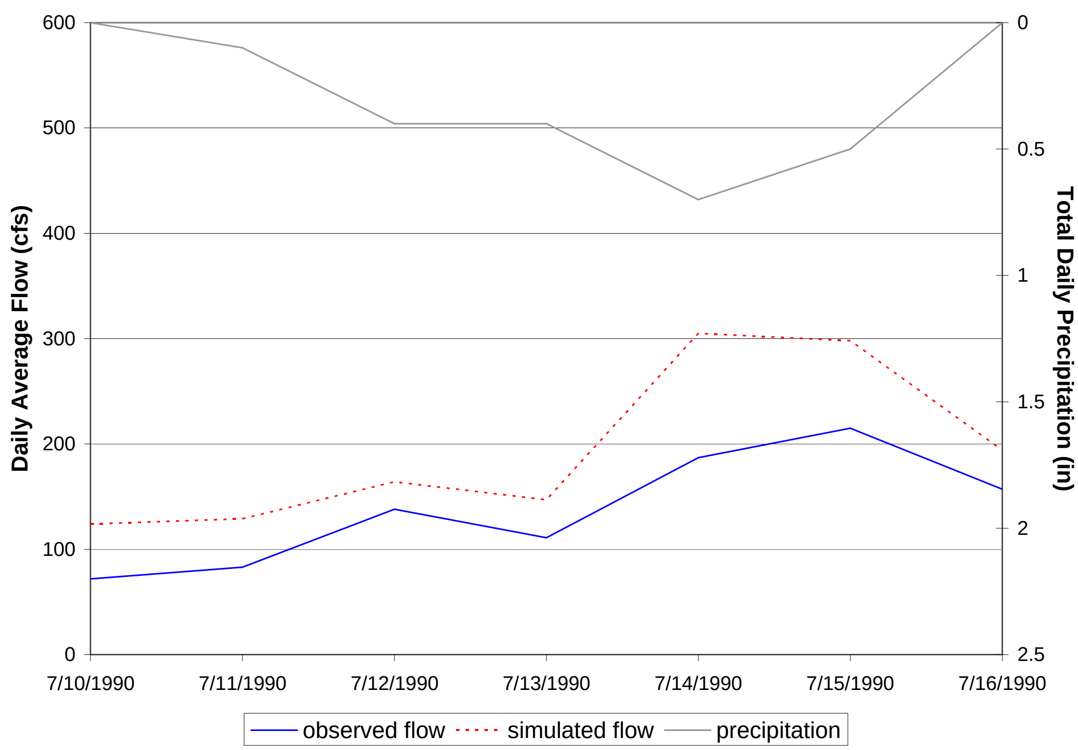

Figure 5.5. Observed and simulated flows and precipitation for North River for a representative storm in the calibration period.

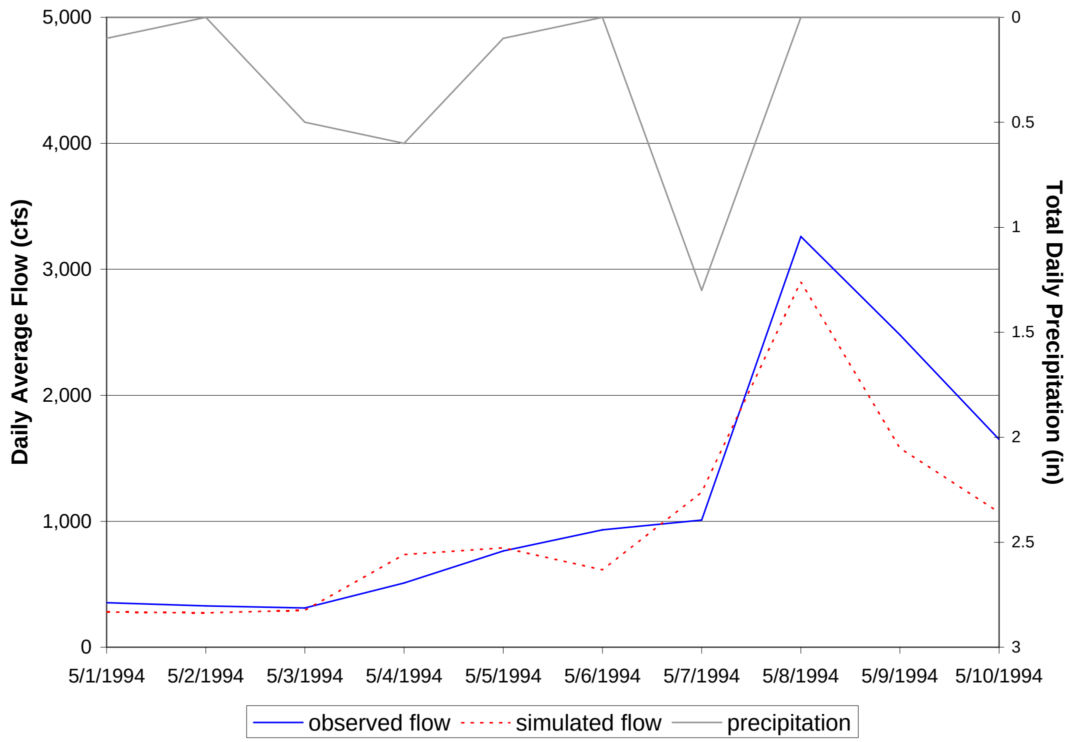

Figure 5.6. Observed and simulated flows and precipitation for North River for a representative storm in the validation period.

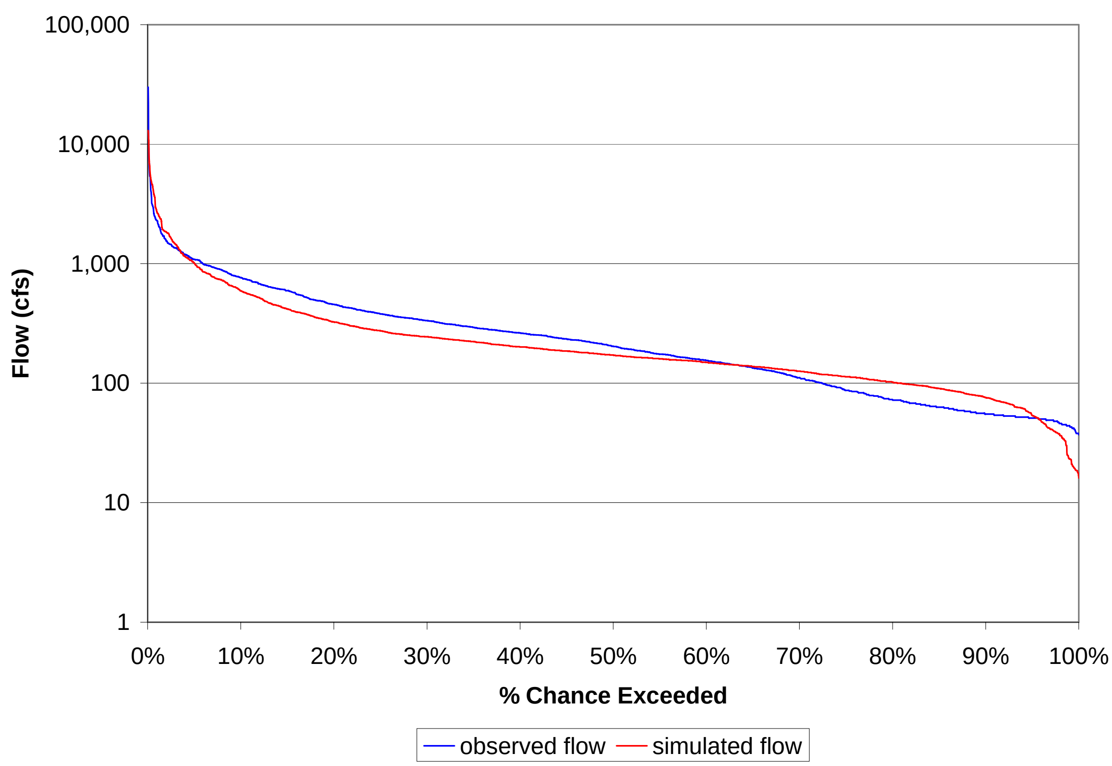

Figure 5.7. Cumulative frequency curves for the calibration period for North River.

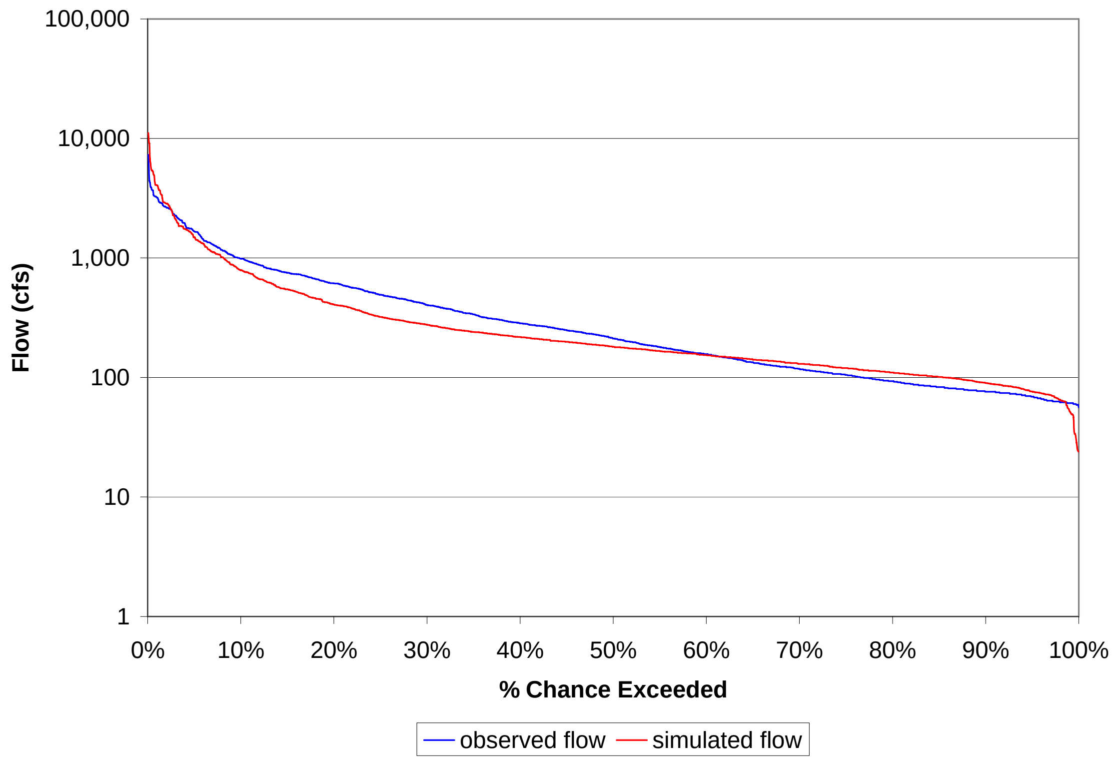

Figure 5.8. Cumulative frequency curves for the validation period for North River.

Selected diagnostic output from the program is listed in Table 5.4 and Table 5.5. The total winter runoff and total summer runoff errors are considered in the HSPEXP term 'seasonal volume error' (see Table 5.3). The errors for seasonal volume error were 3.5% for the calibration period and 8.8% for the validation period; both are within the required range of ±10%.

Table 5.4. Summary statistics for the calibration period for North River.

	Simulated	Observed	Error (%)	Criterion
Total Runoff (in)	57.610	63.724	-9.6	10%
Average Annual Total Runoff (in)	11.52	12.74	-9.6	10%
Total of Highest 10% of flows (in)	27.330	27.525	-0.7	15%
Total of Lowest 50% of flows (in)	10.010	9.195	+8.9	10%
Total Winter Runoff (in)	14.580	14.277	+2.1	na
Total Summer Runoff (in)	9.060	9.186	-1.4	na
Coefficient of Determination, r^2	0.49			

na = not applicable; these are not criteria directly considered by HSPEXP

Table 5.5. Summary statistics for the validation period for North River.

	Simulated	Observed	Error (%)	Criterion
Total Runoff (in)	62.880	67.825	-7.3	10%
Average Annual Total Runoff (in)	14.52	15.65	-7.3	10%
Total of Highest 10% of flows (in)	32.420	30.046	+7.9	15%
Total of Lowest 50% of flows (in)	9.470	8.899	+6.4	10%
Total Winter Runoff (in)	20.360	20.332	+0.1	na
Total Summer Runoff (in)	7.800	8.544	-8.7	na
Coefficient of Determination, r^2	0.38			

na = not applicable; these were not criteria directly considered by HSPEXP

Flow partitioning for the North River hydrologic model calibration and validation is shown in Table 5.6. When the observed flow data were evaluated using HYSEP, the baseflow indices for the calibration and validation periods were both 0.55. The actual baseflow indices for the simulated data are presented in Table 5.6; the baseflow indices predicted by HYSEP for the simulated data are also presented. There is a small discrepancy between the two, as would be expected. We feel the simulated baseflow indices shown in Table 5.6 match the observed values well. The final calibrated hydrology parameters can be found in Table 5.10 at the end of the next section.

Table 5.6. Flow partitioning for the calibration and validation periods for North River.

Average Annual Flow	Calibration	Validation
Total Annual Runoff (in)	11.52	14.52
Surface Runoff (in)	1.22 (11%)	2.03 (14%)
Interflow (in)	4.89 (42%)	6.78 (47%)
Baseflow (in)	5.41 (47%)	5.71 (39%)
Baseflow Index (HSPF)	0.47	0.39
Baseflow Index (HYSEP)	0.50	0.44

The calibration met all the acceptance criteria in both the calibration period and the validation period. This indicates that the developed hydrologic model produces an acceptable prediction of North River flows.

5.4.2. Water Quality Calibration

Most of the area in North River (76%) is covered by previously developed bacteria TMDLs. Each of these watersheds with previously developed TMDLs has a corresponding HSPF input file the previous contractors used to simulate bacteria. These files were calibrated during previous TMDL studies. These files were used in this study to generate bacteria concentrations at the outlet of each watershed with a previously developed TMDL. The calibrated hydrology model from this study was used to obtain a flow rate at the outlet of each watershed with a previously developed TMDL. The concentration and flow rate were multiplied together for each watershed with a previously developed TMDL and then input as a direct source at the appropriate location in the area not covered by a previously developed TMDL. In practical terms, this was accomplished using the GENER block in HSPF to multiply the two timeseries together. Thus, the bacteria loadings in the areas with previously developed TMDLs were not altered during the water quality calibration for North River.

The water quality calibration was performed at an hourly time step using the HSPF model. Three water quality monitoring stations were used in the calibration: 1BNTH036.96, 1BNTH029.30, and 1BNTH014.08. Each was calibrated to a different period. Data from station 1BNTH036.96 were used to calibrate the model from September 1, 1994 to June 30, 2003 – this period contains all observed data available for this station. Data from station 1BNTH029.30 were used to calibrate the model from August 1, 2001 to June 30, 2003 – again, the observed period of record. These first two stations are located upstream of any confluence with streams with previously developed TMDLs. Data from station 1BNTH014.08 were used to calibrate the model from September 1, 1993 to February 28, 1995. This period was chosen to correspond with the calibration periods of many of the watersheds that have previously developed TMDLs. By using this period, the best available simulated data from those watersheds can be used to create the best possible calibration at station 1BNTH014.08. Output from the HSPF model was generated as an hourly timeseries and daily average timeseries of fecal coliform concentration at three subwatershed outlets, corresponding to the three monitoring station locations. *E. coli* concentrations, not directly considered in the water quality calibration, but necessary for the allocation scenarios, were determined using the following translator equation supplied by DEQ:

$$\log_2 EC(cfu/100mL) = -0.0172 + 0.91905 * \log_2 FC(cfu/100mL) \qquad (1)$$

The *E. coli* translator was implemented in the HSPF simulation using the GENER block. During allocation, the geometric mean will be calculated on a monthly basis.

The final calibration parameters are shown in Table 5.10. During the water quality calibration, the only parameter in Table 5.10 that was altered was FSTDEC (first order decay rate of bacteria) - this was increased to 1.80. FSTDEC is an estimated parameter often adjusted within acceptable ranges to achieve model calibration. Additionally, the bacteria production rate for cattle was changed to those levels used in the Pleasant Run TMDL. Due to the size of the North River, it was also assumed that animals (livestock and wildlife) in the downstream portions of North River would be less likely to defecate in the water. The percent of beef cattle with stream access was reduced to 1% for these downstream areas. The wildlife defecation in streams was reduced to 25% of the original assumed value for these downstream areas. In upstream areas, cattle and wildlife access were reduced by a factor of two in most subwatersheds. Cattle stream access in subwatershed 20 was doubled to account for increased bacteria observations at a station in that subwatershed.

Bacterial Source Tracking information was collected at station NTH000.18 for 12 months, from July 2003 to June 2004. The results of this sampling are presented in Table 5.7. The weighted average results presented are weighted based on number of isolates, overall concentration of bacteria in the sample, and flow rate.

Table 5.7. Minimum, maximum, and weighted average BST results for 12 months of samples at Station 1BNTH000.18.

***E. coli* Conc. (cfu/100 mL)**	**Livestock (%)**	**Wildlife (%)**	**Human (%)**	**Pet (%)**
1,808[1] **(6; 20,000)[2]**	61.38 **(15; 84)**	38.18 **(12; 85)**	0.21 **(0; 38)**	0.23 **(0; 21)**

[1]reported concentration is the average of concentrations from all 12 samples
[2]numbers in parentheses indicate the range of concentrations (*E. coli*) or BST percent contributions (other columns) over the 12 samples

Due to the nature of the water quality modeling, it was impossible to conduct a thorough source breakdown for the simulated North River TMDL watershed. Source contributions from the watersheds with previously developed TMDLs could not be classified at the watershed outlet. Due to this condition, it is impossible to correlate the observed and simulated source breakdown data. However, the data are presented for reference (Table 5.8).

Table 5.8. Simulated minimum, maximum, and weighted daily average bacteria contributions for the outlet of North River.

Livestock (%)	**Wildlife (%)**	**Human (%)**	**Pet (%)**	**Interflow and Groundwater (%)**
90.51 **(0; 97)[1]**	5.12 **(0; 79)**	1.86 **(0; 34)**	1.32 **(0; 29)**	1.18 **(0; 85)**

[1]numbers in parentheses indicate the range of percent contributions over a 5-year period (1995-1999)

The simulated fecal coliform concentrations agree well with the observed fecal coliform concentrations at all three calibration locations. Plots of the observed data with average daily simulated fecal coliform concentrations are shown in Figure 5.9, Figure 5.11, and Figure 5.13. It is important to note in these figures that the lower cap on observed values is 100 cfu/100 mL; the upper cap is 8,000 cfu/100 mL. As one would not expect the observed value from a grab sample to precisely match the simulated average daily value for a particular day, Figure 5.10, Figure 5.12, and Figure 5.14 present the range of concentrations simulated on each day. One would expect the observed values to fall within this range.

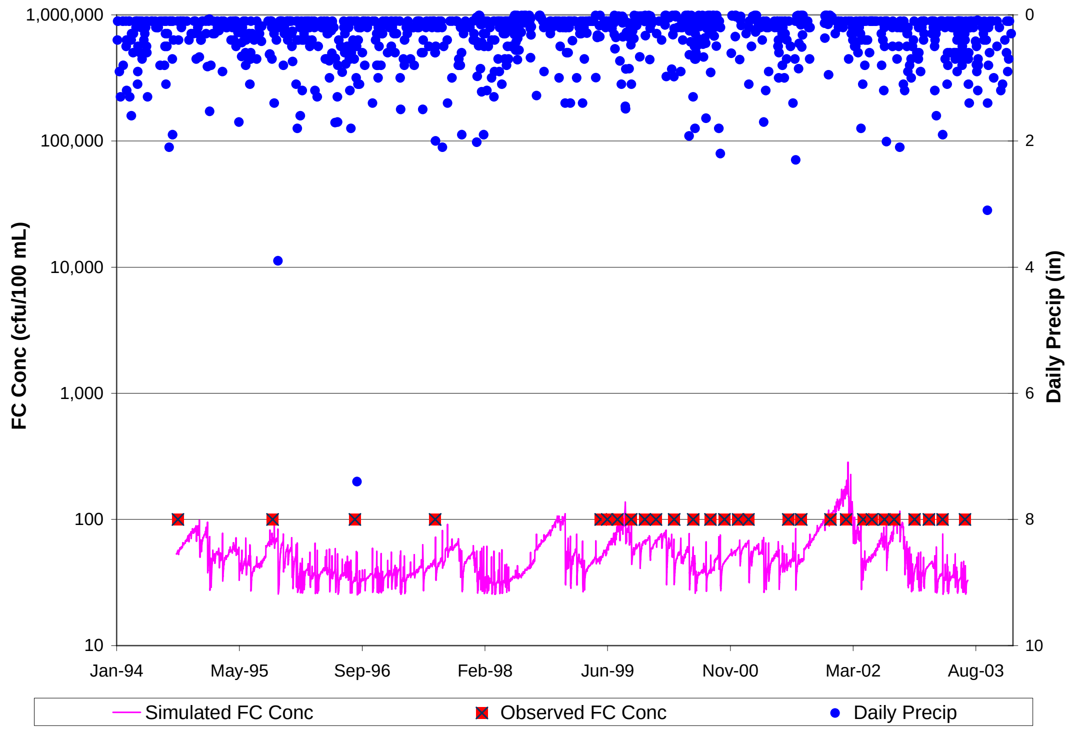

Figure 5.9. Observed and simulated fecal coliform concentrations at station 1BNTH036.96.

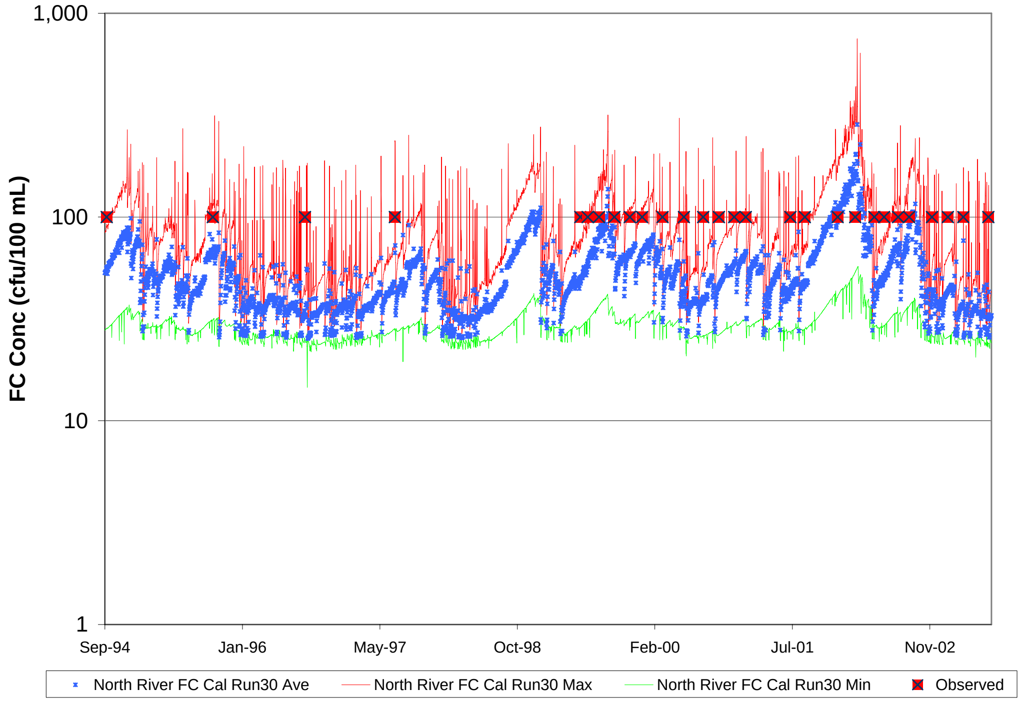

Figure 5.10. Observed fecal coliform data plotted with the daily maximum, minimum, and average simulated fecal coliform values for station 1BNTH036.96.

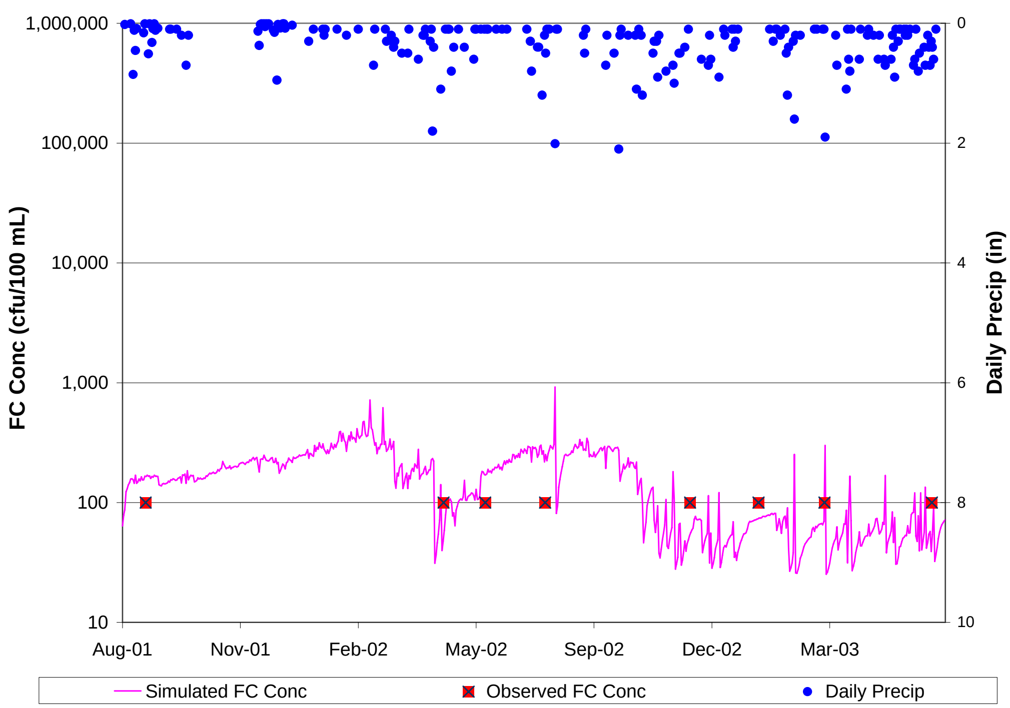

Figure 5.11. Observed and simulated fecal coliform concentrations at station 1BNTH029.30.

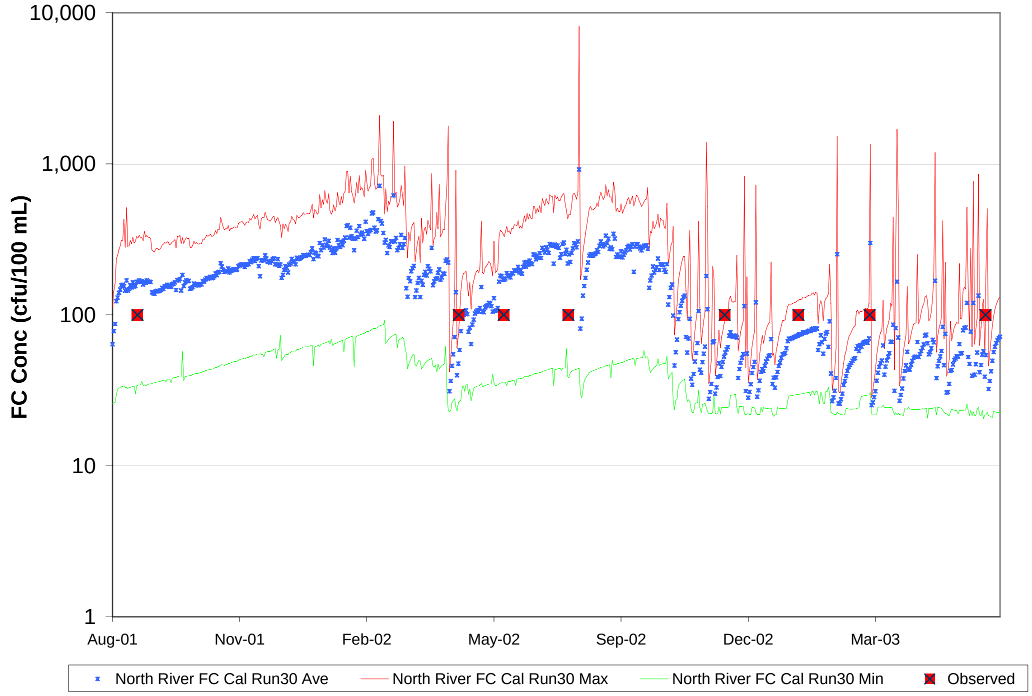

Figure 5.12. Observed fecal coliform data plotted with the daily maximum, minimum, and average simulated fecal coliform values at station 1BNTH029.30.

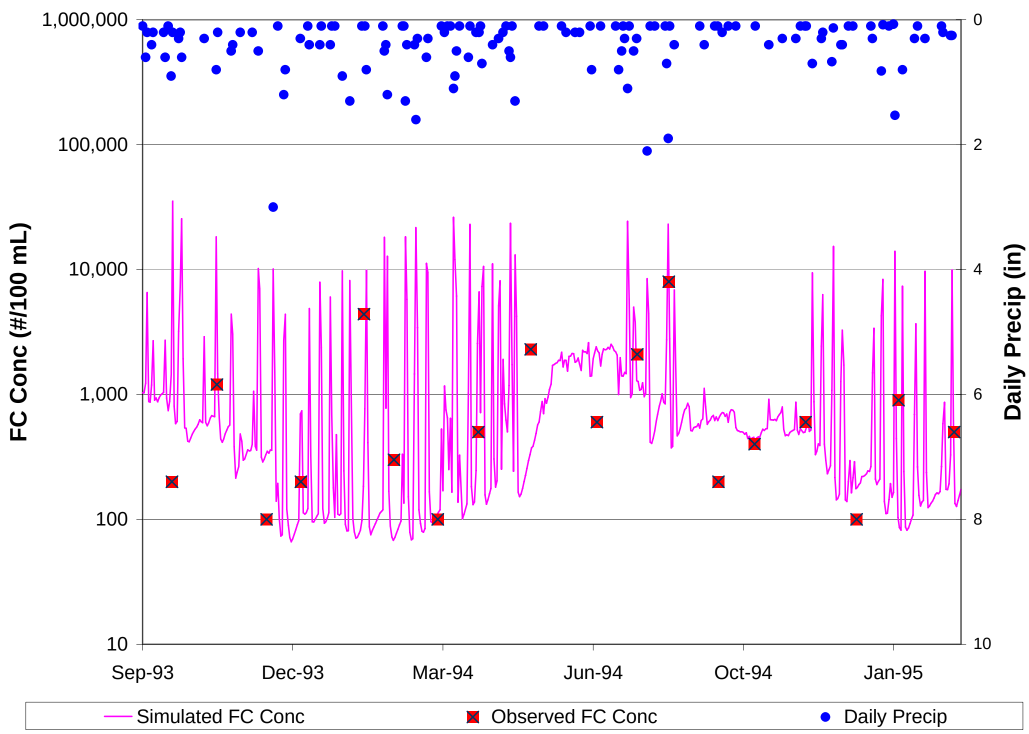

Figure 5.13. Observed and simulated fecal coliform concentrations at station 1BNTH14.08.

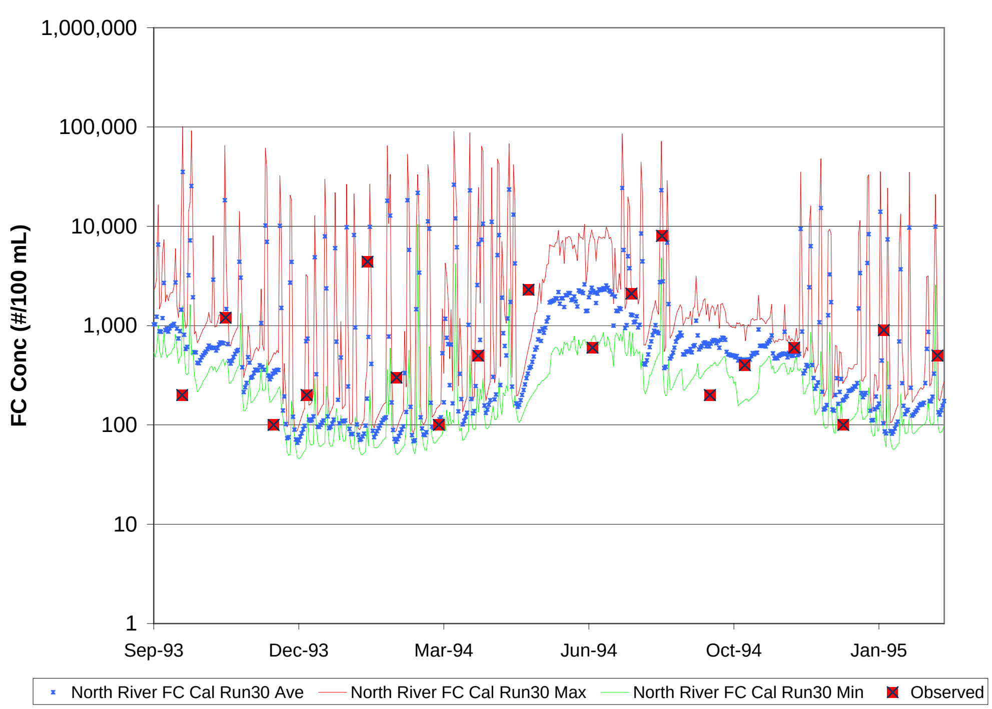

Figure 5.14. Observed fecal coliform data plotted with the daily maximum, minimum, and average simulated fecal coliform values at station 1BNTH014.08.

The observed and simulated geometric means and violation rates for all stations are shown in Table 5.9. As can be seen in this table, the simulated values closely match the observed values. The lower cap on observed data was 100 cfu/100 mL – thus the actual observed values for the stations in Table 5.9 are likely lower than reported. Because the observed samples were collected on a monthly basis, a comparison of violations of the monthly geometric mean criterion cannot be conducted.

Table 5.9. Simulated and observed geometric means and violation rates for the three calibration locations in North River.

Station ID	**NTH036.96 (sub-watershed 22)**		**NTH029.30 (sub-watershed 20)**		**NTH014.08 (sub-watershed 08)**	
	Observed	**Simulated**	**Observed**	**Simulated**	**Observed**	**Simulated**
Instantaneous Standard Violation Rate	**0%**	**0%**	**0%**	**1%**	**61%**	**60%**
Geometric Mean of All Data Points (cfu/100 mL)	**100**	**51**	**100**	**126**	**541**	**554**

The final parameters used in the calibration and validation hydrology and water quality simulations are listed in Table 5.10.

Table 5.10. Final calibrated parameters for North River.

Parameter	Definition	Units	FINAL CALIBRATION	FUNCTION OF…	Appendix Table (if applicable)
PERLND					
PWAT-PARM2					
FOREST	Fraction forest cover	none	1.0 forest, 0.0 other	Forest cover	
LZSN	Lower zone nominal soil moisture storage	inches	5.0	Soil properties	
INFILT	Index to infiltration capacity	in/hr	0.01-0.51[a]	Soil and cover conditions	1
LSUR	Length of overland flow	feet	100-503	Topography	1
SLSUR	Slope of overland flowplane	none	0.009-0.362	Topography	1
KVARY	Groundwater recession variable	1/in	0.0	Calibrate	
AGWRC	Base groundwater recession	none	0.99 forest, 0.98 other	Calibrate	
PWAT-PARM3					
PETMAX	Temp below which ET is reduced	deg. F	40	Climate, vegetation	
PETMIN	Temp below which ET is set to zero	deg. F	35	Climate, vegetation	
INFEXP	Exponent in infiltration equation	none	2	Soil properties	
INFILD	Ratio of max/mean infiltration capacities	none	2	Soil properties	
DEEPFR	Fraction of GW inflow to deep recharge	none	0.06	Geology	
BASETP	Fraction of remaining ET from baseflow	none	0	Riparian vegetation	
AGWETP	Fraction of remaining ET from active GW	none	0	Marsh/wetlands ET	
PWAT-PARM4					
CEPSC	Interception storage capacity	inches	monthly[b]	Vegetation	2
UZSN	Upper zone nominal soil moisture storage	inches	monthly[b]	Soil properties	3
NSUR	Mannings' n (roughness)	none	0.2 residential, 0.3 pasture, 0.35 crop, 0.45 forest	Land use, surface condition	
INTFW	Interflow/surface runoff partition parameter	none	3.0	Soils, topography, land use	
IRC	Interflow recession parameter	none	0.6	Soils, topography, land use	
LZETP	Lower zone ET parameter	none	monthly[b]	Vegetation	4

Table 5.10. Final calibrated parameters for North River. (continued)

Parameter	Definition	Units	FINAL CALIBRATION	FUNCTION OF…	Appendix Table (if applicable)
QUAL-INPUT					
SQO	Initial storage of constituent	#/ac	$0x10^{10}$[c]	Land use	
POTFW	Washoff potency factor	#/ton	0		
POTFS	Scour potency factor	#/ton	0		
ACQOP	Rate of accumulation of constituent	#/day	monthly[b]	Land use	5
SQOLIM	Maximum accumulation of constituent	#	9 x ACQOP[b]	Land use	6
WSQOP	Wash-off rate	in/hr	2.4	Land use	
IOQC	Constituent conc. in interflow	#/ft3	16997 residential, 8496 other	Land use	
AOQC	Constituent conc. in active groundwater	#/ft3	11331 residential, 5664 other	Land use	
IMPLND					
IWAT-PARM2					
LSUR	Length of overland flow	feet	250	Topography	
SLSUR	Slope of overland flowplane	none	0.18	Topography	
NSUR	Mannings' n (roughness)	none	0.1	Land use, surface condition	
RETSC	Retention/interception storage capacity	inches	0.125	Land use, surface condition	
IWAT-PARM3					
PETMAX	Temp below which ET is reduced	deg. F	40	Climate, vegetation	
PETMIN	Temp below which ET is set to zero	deg. F	35	Climate, vegetation	
IQUAL					
SQO	Initial storage of constituent	#/ac	$1x10^7$		
POTFW	Washoff potency factor	#/ton	0		
ACQOP	Rate of accumulation of constituent	#/day	$1x10^7$	Land use	
SQOLIM	Maximum accumulation of constituent	#	$3x10^7$	Land use	
WSQOP	Wash-off rate	in/hr	1.0	Land use	
RCHRES					
HYDR-PARM2					
KS	Weighting factor for hydraulic routing		0.3		
GQUAL					
FSTDEC	First order decay rate of the constituent	1/day	1.80		
THFST	Temperature correction coeff. for FSTDEC		1.05		

[a]Varies with land use
[b]Varies by month and with land use
[c]note that the simulation was started seven years in advance of calibration to initialize storage

CHAPTER 6: TMDL ALLOCATIONS

The objective of a TMDL is to allocate allowable loads among different pollutant sources so that the appropriate control actions can be taken to achieve water quality standards (USEPA, 1991).

6.1. Background

The objective of the bacteria TMDL for North River was to determine what reductions in fecal coliform and *E. coli* loadings from point and nonpoint sources are required to meet state water quality standards. The state water quality standards for *E. coli* used in the development of the TMDL were 126 cfu/100mL (calendar-month geometric mean) and 235 cfu/100mL (single sample maximum). The TMDL considers all sources contributing fecal coliform and *E. coli* to North River. The sources can be separated into nonpoint and point (or direct) sources. The different sources in the TMDL are defined in the following equation:

$$TMDL = WLA + LA + MOS \qquad [6.1]$$

where,

WLA = wasteload allocation (point source contributions);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety.

While developing allocation scenarios to implement the bacteria TMDL, an implicit margin of safety (MOS) was used by using conservative estimations of all factors that would affect the bacteria loadings in the watershed (e.g., animal numbers, production rates, and contributions to streams). These factors were estimated in such a way as to represent the worst-case scenario; i.e., these factors would describe the worst stream conditions that could exist in the watershed. Creating a TMDL with these conservative estimates ensures that the worst-case scenario has been considered and that no water quality standard violations will occur if the TMDL plan is followed.

When developing a bacteria TMDL, the required bacteria load reductions are modeled by decreasing the amount of bacteria applied to the land surface; these reductions are presented in the tables in Section 6.2b. In the model, this has the effect of reducing the amount of bacteria that reaches the stream, the ultimate goal of the TMDL. Thus, the reductions called for in Section 6.2 indicate the need to decrease the amount of bacteria reaching the stream in order to meet the applicable water quality standard. The reductions shown in Section 6.2 are not intended to infer that agricultural producers should reduce their herd size, or limit the use of manures as fertilizer or soil conditioner. Rather, it is assumed that the required reductions from affected agricultural source categories (cattle direct deposit, cropland, etc.) will be accomplished by implementing BMPs like filter strips, stream fencing, and off-stream watering; and that required reductions from residential source categories will be accomplished by repairing aging septic systems, eliminating straight pipe discharges, and other appropriate measures included in the TMDL Implementation Plan.

A period of five years was used for source allocation. Observed meteorological data from the nearby Dale Enterprise weather station were extracted for the period 1988 to 1992 and used in the allocation. This period was selected because it incorporates average rainfall, low rainfall, and high rainfall years; and the climate during this period caused a wide range of hydrologic events including both low and high flow conditions. The dates in all allocation graphs in this report correspond to the 1988-1992 meteorological years; however, the bacteria loadings used in allocation modeling correspond to anticipated future conditions for the North River TMDL watershed.

The calendar-month geometric mean values used in this report are geometric means of the simulated daily concentrations. Because HSPF was operated with a one-hour time step in this study, 24 hourly concentrations were generated each day. To estimate the calendar-month geometric mean from the hourly HSPF output, we took the arithmetic mean of the hourly values on a daily basis, and then calculated the geometric mean from these average daily values.

The guidance for developing an *E. coli* TMDL offered by VADEQ is to develop input for the model using fecal coliform loadings as the bacteria source in the watershed. Then, VADEQ suggests the use of a translator equation they developed to convert the daily average fecal coliform concentrations output by the model to daily average *E. coli* concentrations (Equation 5.1).

Equation 5.1 was used to convert the fecal coliform concentrations output by HSPF to *E. coli* concentrations. Daily *E. coli* loads were obtained by using the *E. coli* concentrations calculated from the translator equation and multiplying them by the average daily flow. Annual loads were obtained by summing the daily loads and dividing by the number of years in the allocation period.

6.2. North River Bacteria TMDL

6.2.1. Existing Conditions

Analysis of the simulation results for the existing conditions in the watershed (Table 6.1) shows that contributions from pervious land segments are the primary source of *E. coli* in the stream. The results in this table were taken as the average daily contributions for the simulation period, irrespective of the magnitude of the concentration or the flow rate (factors that were considered in the earlier section detailing the source breakdown used in the calibration). Contributions from watersheds with previously developed TMDLs constitute the majority of the in-stream concentration (91%), on average. Considering the area targeted for this TMDL (hydrologic units B16-B18, B23), contributions from the upland pervious land segments account for approximately 51% of the concentration at the watershed outlet. Direct deposition of manure by wildlife and cattle into North River are very close, responsible for approximately 23% and 19% of the mean daily *E. coli* concentration, respectively. The next largest contributors are interflow and groundwater (5%) and straight pipes (3%). Runoff from impervious areas contributed very little to the mean daily *E. coli* concentration.

Table 6.1. Relative contributions of different *E. coli* sources to the overall *E. coli* concentration for the existing conditions in the North River watershed.

Source	Mean Daily *E. coli* Concentration by Source, cfu/100mL	Relative Contribution by Source	Relative Contribution Only B16-B18, B23
All Sources	677		
Watersheds With Previously Developed TMDLs	618	91%	--
Nonpoint source loadings from pervious land segments	30	4%	51%
Direct nonpoint source loadings to the stream from wildlife	14	2%	23%
Direct deposits of cattle manure to stream	11	2%	19%
Interflow and groundwater contribution	2.7	<1%	5%
Straight-pipe discharges to stream	1.5	<1%	3%
Nonpoint source loadings from impervious land use	0.05	<1%	<1%

The contribution of each of the sources detailed in Table 6.1 to the calendar-month geometric *E. coli* concentration is shown in Figure 6.1. Although there are dates in Figure 6.1, these data should not be compared to other information from that period, as the bacteria loadings used in the model are not for the conditions at that time, but for the conditions expected to be representative of the watershed in the near future. The 'PLS' category in Figure 6.1 includes the PLS and interflow and groundwater categories from Table 6.1. Because contributions from impervious surfaces only occur during rainfall events, there are many days with zero concentration from impervious areas; therefore, the calendar month geometric mean of impervious contributions is zero and does not appear in Figure 6.1.

As one would expect given the dominance of the contributions from watersheds with previously developed TMDLs in the daily *E. coli* concentration in Table 6.1, the contributions from watersheds with previously developed TMDLs dominate the calendar-month geometric mean *E. coli* concentration. The geometric mean concentration from all sources, watersheds with previously developed TMDLs, and livestock direct deposit rises in the summer and falls in the winter. This is due to increase time spent in streams by livestock during summer months, combined with lower flow volumes; these two factors combine to increase bacteria concentrations during the summer. Pervious surface contributions and contributions from wildlife direct deposit rise and fall with varying flow rates but are very similar in their geometric mean concentrations throughout the year. Straight pipes maintain a steady, albeit much lower, geometric mean concentration.

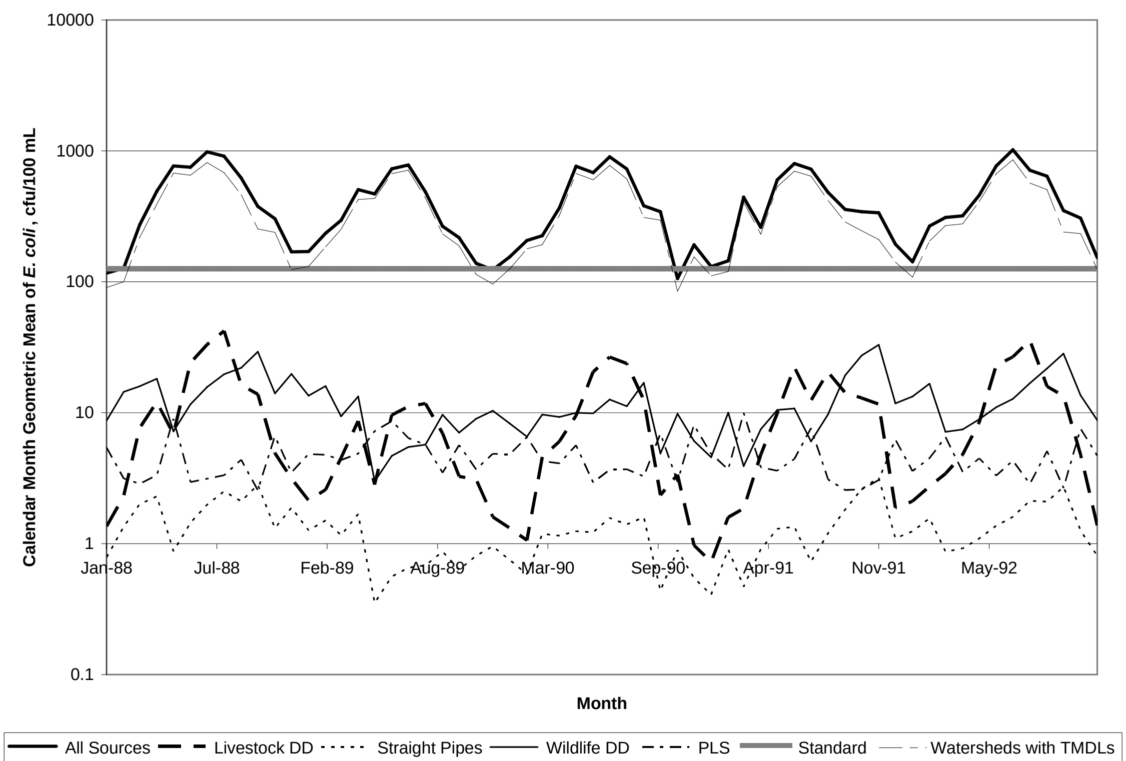

Figure 6.1. Relative contributions of different *E. coli* sources to the calendar-month geometric mean *E. coli* concentration for existing conditions in the North River watershed.

6.2.2. Future Conditions

To ensure that the developed TMDL will be applicable in the future, expected urban development in the North River TMDL watershed was considered during allocation. The majority of the North River TMDL watershed is covered in forest land or other rural area not likely to be urbanized. However, it is expected that some urban development will occur between Bridgewater and Harrisonburg. The Rockingham County Comprehensive Plan (Rockingham County Community Development, 2005) was consulted to determine what changes might be expected in the future. A map was available in this plan for the expected development in 2020; this was used to develop our future buildout conditions.

The majority of the development that is expected to occur between Bridgewater and Harrisonburg will take place in the Cooks Creek watershed – outside of the area considered during allocations. Some development is planned in subwatersheds 6, 7, 11, and 12 (Figure 6.2). The 'current' 2020 land use in Figure 6.2 is what is planned for 2020. The 'future' land use is what is planned beyond 2020. The 'current' 2020 conditions were considered in developing the future buildout scenario for the TMDL. It was assumed that the 'incorporated' area would undergo no further significant development. The buildout calculations described here apply to the 'commercial' and 'residential' land use types in Figure 6.2 that fall within the relevant subwatershed boundaries.

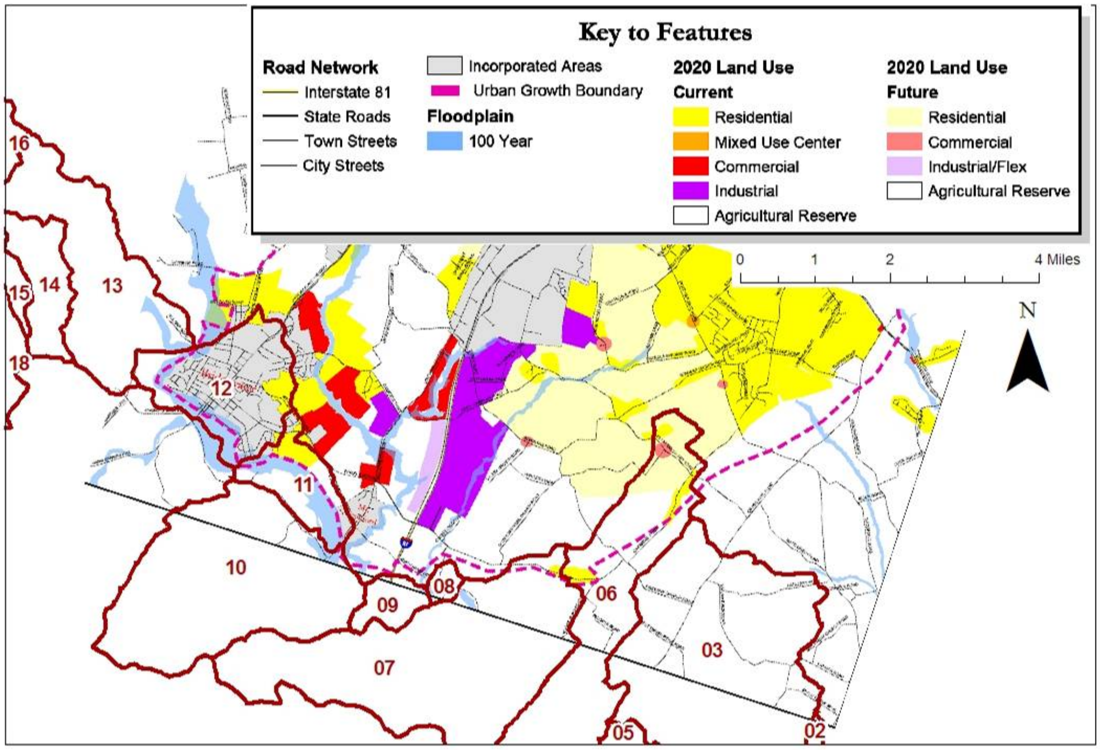

Figure 6.2. Rockingham County Comprehensive Plan 2020 Conditions overlain with North River subwatershed boundaries. Comprehensive plan and key from Rockingham County Community Development, 2005.

Table 6.2 summarizes the areas of non-urban land use types (forest, cropland, and pasture) that fall within the 'commercial' and 'residential' projected land use categories in Figure 6.2. With the exception of 0.7 acres of pasture that will become commercial (thus classified as HDR, see Chapter 3), all the areas in Table 6.2 will be converted to the low density residential (LDR) land use during allocations.

Table 6.2. Areas in non-urban land use slated for development by 2020, acres; numbers in parentheses indicate the percentage these losses are of the total area of the land use type in that subwatershed.

Subwatershed	Non-Urban Land Use Type		
	Cropland	Forest	Pasture
6	2.62 (1%)	22.61 (2%)	83.02 (3%)
7	0.75 (<1%)	1.83 (<1%)	11.59 (<1%)
11	20.17 (19%)	8.85 (6%)	72.38 (17%)
12	11.41 (9%)	23.98 (6%)	66.78 (13%)

The land use changes will result in changes in the animal and human populations as well. As mentioned in Chapter 4, the locations of dairy and poultry facilities were known; none of these locations fell within the 'residential' or 'commercial' land uses projected for 2020; therefore these animal numbers were not changed for future conditions. Other livestock (beef, horse, ewe, and goat) populations were decreased by the fraction of pasture lost in each subwatershed (Table 6.2). Wildlife populations were adjusted according to the losses of their acceptable habitat types (see Chapter 4). The number of houses in each subwatershed was increased according to the existing housing density. This resulted in a corresponding increase in the pet population. Houses added to subwatersheds 11 and 12 were assumed to be connected to the sewer system, considering the proposed expansion of the North River WWTF to 28 MGD. Houses added in subwatersheds 6 and 7 were not assumed connected to the sewer system and were added to the 'new' category of houses on septic systems – with the corresponding assumed 3% failure rate (see Chapter 4). The total numbers lost and added as a result of the buildout condition are summarized in Table 6.3.

Table 6.3. Populations subtracted and added as a result of the buildout condition; absence of an animal type indicates no change was made to that population.

	Population Subtracted							Population Added		
subwatershed	raccoon	muskrat	wild turkey	beef	horses	ewes	goats	houses on sewer	houses with septic systems	pets
6	1	0	1	6	1	2	1	0	185	185
7	0	0	0	0	0	0	0	0	94	94
11	0	25	1	4	1	2	1	100	0	100
12	1	0	1	4	1	2	1	192	0	192

6.2.3. Allocation Scenarios

A variety of allocation scenarios were evaluated to meet the *E. coli* TMDL goal of a calendar-month geometric mean of 126 cfu/100mL and the single sample limit of 235 cfu/100mL. The scenarios and results are summarized in Table 6.4; recall that these reductions are those used for modeling, and implementation of these reductions will require implementation of BMPs as discussed at the beginning of this chapter. Two successful scenarios were found to meet the standards for the North River.

Table 6.4. Bacteria allocation scenarios for the North River TMDL watershed.

Scenario Number	% Violation of *E. coli* standard		Required Fecal Coliform Loading Reductions to Meet the *E coli* Standards,%					
	Geomean	Single Sample	Cattle DD	Loads from Cropland	Loads from Pasture	Wildlife DD	Straight Pipes	Loads from Residential
Unsuccessful Scenarios								
Baseline Future Conditions	93%	63%	0	0	0	0	0	0
NR1 – Previous TMDLs Met	37%	5%	0	0	0	0	0	0
NR2	2%	0%	45	75	95	0	100	80
NR3	0%	0.05%	50	80	90	0	100	80
Successful Scenarios								
NR4	0%	0%	50	75	92	0	100	80
NR5	0%	0%	50	90	90	0	100	90

As can be seen from the Existing Conditions in Table 6.4, the initial violation rates for the geometric mean and single sample standards for North River were extreme. Scenario NR1 was developed under the assumption that TMDLs that have already been developed within the North River watershed will be met. This significantly decreased the violation of both the instantaneous and geometric mean standards. This assumption was held throughout the rest of the allocation scenarios, allowing isolation of the reductions needed for hydrologic units B16-B18 and B23. That is, the reductions presented in Table 6.4 apply only to the area of the watershed not covered by a previously developed TMDL. Given the concern of the local steering committee regarding failing septic systems that 'fail downward' and contaminate interflow and groundwater, scenarios NR2-NR5 include a 50% reduction in loads to interflow and groundwater to bring the concentrations from those water sources down to background levels.

Table 6.2 includes two categories of scenarios: those that were successful and those that were unsuccessful. Presentation of the unsuccessful scenarios illustrates the need for the reductions called for in the successful scenarios. In unsuccessful scenario NR2, straight pipes were eliminated and large reductions were taken from direct deposition of cattle in the streams (45%), cropland contributions (75%), pasture contributions (95%), and residential contributions (80%). The continued violation of the geometric mean standard under this scenario evidenced the need for greater reductions in cattle direct deposit. In scenario NR3, cattle direct deposit was reduced by 50%, loads from cropland by 80%, loads from pasture by 90%, and loads from residential areas by 80%. The increase in the cattle direct deposit reductions under this scenario eliminated the geometric mean violations; however, the lower reductions from pasture areas caused violations of the instantaneous standard. Successful allocation scenario NR4 resulted from an increase in pasture reductions (92%). Successful allocation scenario NR5 resulted from a much greater increase in reductions from cropland (90%) and residential areas (90%) to allow the pasture reduction to remain at 90%.

Scenarios NR4 and NR5 meet both *E. coli* standards and would be acceptable targets for implementation. During implementation planning, the implementation plan steering committee could choose either successful scenario upon notification to EPA. The local steering committee that assisted with TMDL development favored a balance of reductions between all land sources, so Scenario NR5 was selected as the recommended allocation scenario. The calculated TMDL loads and associated graphs and tables in this report are for Scenario NR5. This scenario requires a 50% reduction in loadings due to cattle stream access and 100% reduction in straight pipes. It also requires a 90% reduction in loadings originating from the major human-impacted areas: cropland, pasture, and residential. In conjunction with the 90% reduction in surface water loads from the residential area, septic system repairs are expected to reduce the load to groundwater by 50%, returning concentrations in interflow and groundwater to background levels. The concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 6.3 for the TMDL allocation (Scenario NR5), along with the standards.

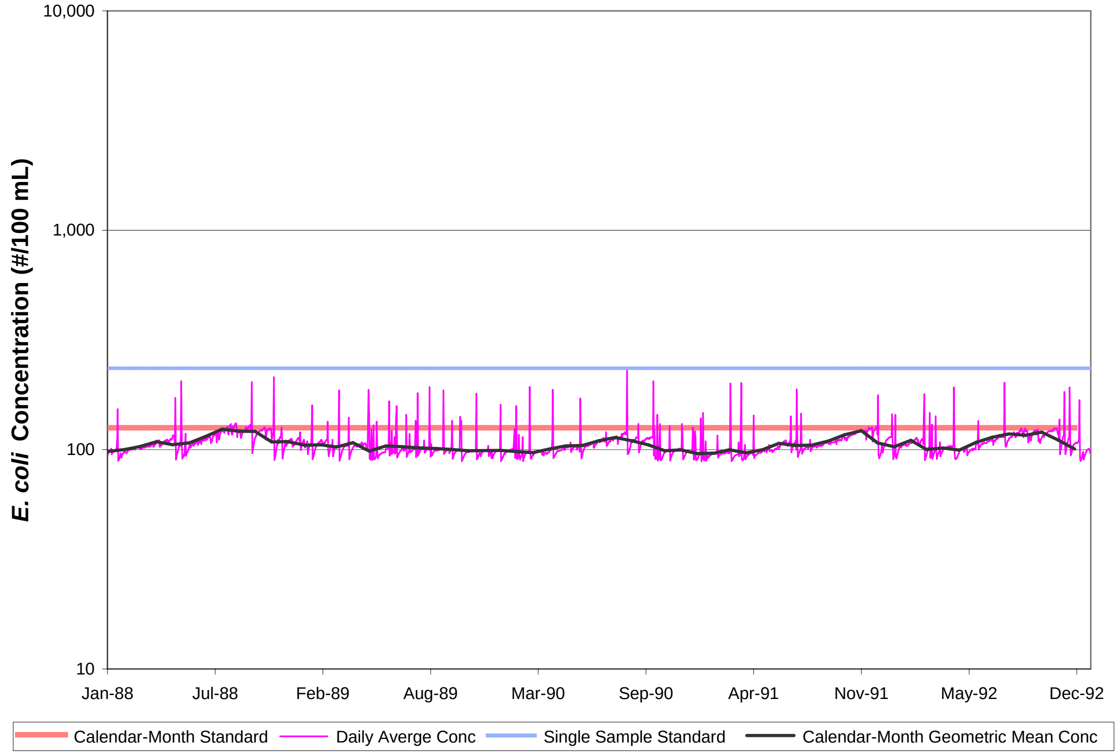

Figure 6.3. Calendar-month geometric mean standard, single sample standard, and successful *E. coli* TMDL allocation (Allocation Scenario NR5) for the North River watershed.

Loadings for existing conditions and the TMDL allocation scenario (Scenarios NR5) are presented for nonpoint sources by land use in Table 6.5 and for direct nonpoint sources in Table 6.6.

Table 6.5. Annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario NR5.

Land use Category	Existing Conditions: Existing conditions load (× 10^{12} cfu/yr)	Existing Conditions: Percent of total land deposited load from nonpoint sources	Future Conditions: Future conditions load (× 10^{12} cfu/yr)	Future Conditions: Percent of total land deposited load from nonpoint sources	Allocation Scenario: TMDL nonpoint source allocation load (× 10^{12} cfu/yr)	Allocation Scenario: Percent reduction from future load
Cropland	2,340	3.6%	2,310	3.6%	231	90%
Pasture	58,800	91.6%	58,600	91.3%	5,860	90%
Residential[a]	1,750	2.7%	1,860	2.9%	186	90%
Impervious[b]	1.81	<1%	2.14	<1%	0.214	90%
MS4 Imperv.[c]	0.642	<1%	0.678	<1%	0.0678	90%
Forest	1,380	2.1%	1,380	2.2%	1,380	0%
Total	64,300	100%	64,200	100%	7,660	88%

[a] Includes loads applied to pervious areas of both High and Low Density Residential
[b] Includes loads applied to impervious areas of both High and Low Density Residential
[c] Impervious areas inside the MS4 for Bridgewater

Table 6.6. Annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation for scenario NR5.

Source	Existing Condition: Existing conditions load (× 10^{12} cfu/yr)	Existing Condition: Percent of total direct deposited load from direct nonpoint sources	Future Conditions: Future conditions load (× 10^{12} cfu/yr)	Future Conditions: Percent of total direct deposited load from direct nonpoint sources	Allocation Scenario: TMDL direct nonpoint source allocation load (× 10^{12} cfu/yr)	Allocation Scenario: Percent reduction
Cattle in streams	70.8	43%	70.8	43%	35.4	50%
Straight Pipes	8.20	5%	8.20	5%	0	100%
Wildlife in Streams	85.8	52%	85.7	52%	85.7	0%
Total	165	100%	165	100%	121	27%

The fecal coliform loads presented in Table 6.5 and Table 6.6 are the fecal coliform loads that result in in-stream *E. coli* concentrations that meet the applicable *E. coli* water quality standards after application of the VADEQ fecal coliform to *E. coli* translator to the HSPF predicted mean daily fecal coliform concentrations.

6.2.4. Waste Load Allocation

Waste load allocations (WLAs) were assigned to eighteen point source facilities located in the North River TMDL watershed (Table 6.7). The point sources in this table include only those found within B16-B18 and B23; other point sources have been addressed in previously developed TMDLs. The point sources were represented in the allocation scenarios by their current permit conditions; no reductions were required from the point sources in the TMDL. Current permit requirements are expected to result in attainment of the *E. coli* WLA as required by the TMDL. Point source contributions to bacteria concentrations, even in terms of maximum flow, are minimal. In addition, the point source facilities are required to discharge at or below the bacteria water quality criterion and therefore cannot cause a violation of that criterion without also violating the discharge permit. Because the permits for these facilities already protect against violating the bacteria water quality standard, there is no need to modify the existing permits.

Table 6.7. Point Sources Discharging Bacteria in the North River TMDL Watershed.

Permit Number	Flow (gpd)	Permitted FC Conc. (cfu/100 mL)	Permitted FC Load (cfu/year)	Allocated FC Load (cfu/year)	Allocated *E. coli* Load (cfu/year)
VA0060640	28×10^6	200	$7.74*10^{13}$	$7.74*10^{13}$	$4.88*10^{13}$
VA0022349	0.5×10^6	200	$1.38*10^{12}$	$1.38*10^{12}$	$8.71*10^{11}$
16 general	16000	200	$44.16*10^9$	$44.16*10^9$	$27.84*10^9$

In addition to the permitted point sources, a Municipal Separate Storm Sewer System (MS4) permit is in place for the town of Bridgewater (permit number VAR040054). It is assumed that the *E. coli* load originating on the portion of the impervious land segments covered by the MS4 permit (ILS MS4 Load) will be controlled by those permits. The difference between the ILS MS4 allocation load and the future conditions load is 6.10×10^{11} cfu/yr ($6.78 \times 10^{11} - 6.78 \times 10^{10} = 6.10 \times 10^{11}$) (Table 6.5), which is to be mitigated by MS4 regulation requiring implementation of best management practices to reduce pollutants to the "maximum extent practicable."

6.2.5. Summary of North River's TMDL Allocation Scenario for Bacteria

A TMDL for *E. coli* has been developed for North River. The TMDL addresses the following issues:

1. The TMDL meets the calendar-month geometric mean and single sample water quality standards.
2. Because *E. coli* loading data were not available to quantify point or nonpoint source bacterial loads, available fecal coliform loading data were used as input to HSPF. HSPF was then used to simulate in-stream fecal coliform concentrations. The VADEQ fecal coliform to *E. coli* concentration translator was then used to convert the simulated fecal coliform concentrations to *E. coli* concentrations for which the bacteria TMDL was developed.
3. The TMDL was developed taking into account all fecal bacteria sources (anthropogenic and natural) from both point and nonpoint sources.
4. An implicit margin of safety (MOS) was incorporated by utilizing professional judgment and conservative estimates of model parameters.
5. Both high- and low-flow stream conditions were considered while developing the TMDL. In the North River watershed, low stream flow was found to be the environmental condition most likely to cause a violation of the geometric mean criterion; high stream flow conditions after storm events were most likely to cause violations of the single sample criterion; because the TMDL was developed using a continuous simulation model, it applies to both high- and low-flow conditions.
6. Both the flow regime and bacteria loading to North River are seasonal. The TMDL accounts for these seasonal effects.

The selected *E. coli* TMDL allocation that meets both the calendar-month geometric mean and single sample water quality goals requires a 50% reduction in cattle direct deposits to the stream; 100% reduction in straight pipe contributions; and 90% reduction from cropland, pasture, and residential surfaces. The 90% reduction in contributions from residential areas applies to both pervious and impervious loadings; this means that a 90% reduction in source loadings to impervious land surfaces within the MS4 regulated area is needed; it is assumed this reduction will be achieved through the MS4 process. In conjunction with the 90% reduction in surface water loads from the residential area, septic system repairs are expected to reduce the load to groundwater by 50%, returning concentrations in interflow and groundwater to background levels. Using Eq. [6.1], the summary of the bacteria TMDL for North River for the selected allocation scenario (Scenario NR5) is given in Table 6.8. This allocation scenario covers ONLY the area not covered by a previously developed TMDL (B16-B18, B23). In Table 6.8, the WLA for point sources was obtained by multiplying the permitted point source's fecal coliform discharge concentration by its allowable annual discharge. The WLA for the MS4 area was determined as the bacteria load at the watershed outlet originating from the MS4 area. The LA is then determined as the TMDL – WLA.

Table 6.8. Annual *E. coli* loadings (cfu/year) at the watershed outlet used for the North River bacteria TMDL.

Parameter	ΣWLA	ΣLA	MOS[a]	TMDL
E. coli	4.97×10^{13} *(Σ16 general permits=2.788×10^{10}* *VA0060640=4.876×10^{13}* *VA0022349=8.707×10^{11}* *VAR040054=1.22×10^{10})*	14.86×10^{13}	--	19.83×10^{13}

[a]Implicit MOS

For reference, the previously approved TMDLs are summarized in Table 6.9. These apply to the area not considered in the TMDL equation in Table 6.8.

Table 6.9. Previously developed bacteria TMDLs for the contributors to North River.

Watershed	Parameter	ΣWLA	ΣLA	MOS	TMDL
Dry River[1]	Fecal coliform *E. coli*[2]	0.003×10^{14} 0.002×10^{14}	3.74×10^{14} 2.36×10^{14}	0.1974×10^{14} 0.124×10^{14}	3.94×10^{14} 2.48×10^{14}
Mossy Creek	*E. coli*	1.74×10^{9}	1.59×10^{13}	Implicit	1.59×10^{13}
Long Glade	*E. coli*	5.23×10^{9}	2.31×10^{12}	Implicit	2.32×10^{12}
Beaver Creek	*E. coli*	1.22×10^{10}	$1{,}567 \times 10^{10}$	Implicit	$1{,}568 \times 10^{10}$
Middle River[3]	*E. coli*	1.22×10^{13}	8.80×10^{13}	Implicit	1.00×10^{14}
Naked Creek	Fecal coliform *E. coli*[2]	0.006×10^{12} 0.004×10^{12}	$2{,}681 \times 10^{12}$ $1{,}690 \times 10^{12}$	141×10^{12} 88.8×10^{12}	$2{,}822 \times 10^{12}$ $1{,}780 \times 10^{12}$
Mill Creek	Fecal coliform *E. coli*[2]	0 0	$1{,}597 \times 10^{12}$ $1{,}010 \times 10^{12}$	84×10^{12} 53×10^{12}	$1{,}681 \times 10^{12}$ $1{,}060 \times 10^{12}$
Cooks Creek[4]	Fecal coliform *E. coli*[2]	0 0	4.98×10^{13} 3.14×10^{13}	4.98×10^{12} 3.14×10^{12}	5.48×10^{13} 3.45×10^{13}
Pleasant Run	Fecal coliform *E. coli*[2]	0 0	$2{,}381 \times 10^{12}$ $1{,}500 \times 10^{12}$	125.3×10^{12} 78.9×10^{12}	$2{,}506 \times 10^{12}$ $1{,}580 \times 10^{12}$

[1]Dry River includes contributions from Upper Dry River and Muddy Creek
[2]Watersheds with both fecal coliform and *E. coli* listed were developed for fecal coliform; the *E. coli* values have been approximated by multiplying the fecal coliform loads by the ratio of the geometric mean standards (126:200)
[3]Middle River includes contributions from Upper Middle River, Moffett Creek, Lewis Creek, Polecat Draft, and Christians Creek
[4]Cooks Creek includes contributions from Blacks Run

CHAPTER 7: TMDL IMPLEMENTATION AND REASONABLE ASSURANCE

Once a TMDL has been approved by EPA, measures must be taken to reduce pollution levels from both point and not point sources in the stream (see section 7.4.2). For point sources, all new or revised VPDES/NPDES permits must be consistent with the TMDL WLA pursuant to 40 CFR §122.44 (d)(1)(vii)(B) and must be submitted to EPA for approval. The measures for non point source reductions, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the implementation plan. The process for developing an implementation plan has been described in the recent "TMDL Implementation Plan Guidance Manual" (VADCR and VADEQ, 2003), published in July 2003 and available upon request from the DEQ and DCR TMDL project staff or at http://www.deq.state.va.us/tmdl/implans/ipguide.pdf. With successful completion of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

7.1. Staged Implementation

In general, Virginia intends for the required bacteria reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, in agricultural areas of the watershed, the most promising best management practice is livestock exclusion from streams. This has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the cattle deposits themselves and by providing additional riparian buffers.

Additionally, in both urban and rural areas, reducing the human bacteria loading from failing septic systems should be a primary implementation focus because of its health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system repair/replacement program and the use of alternative waste treatment systems.

In urban areas, reducing the human bacteria loading from leaking sewer lines could be accomplished through a sanitary sewer inspection and management program. Other BMPs that might be appropriate for controlling urban wash-off from parking lots and roads and that could be readily implemented may include more restrictive ordinances to reduce fecal loads from pets, improved garbage collection and control, and improved street cleaning.

The iterative implementation of BMPs in the watershed has several benefits:

1. It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. It provides a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

Watershed stakeholders will have opportunity to participate in the development of the TMDL implementation plan. While specific goals for BMP implementation will be established as part of the implementation plan development, the following Stage 1 scenarios are targeted at controllable, anthropogenic bacteria sources and can serve as starting points for targeting BMP implementation activities.

7.2. Stage 1 Scenarios

The goal of the Stage 1 scenarios is to reduce the bacteria loadings from controllable sources (excluding wildlife) such that violations of the instantaneous criterion (235 cfu/100mL) are less than 10 percent. A Stage 1 scenario was generated with the same model setup as was used for the TMDL allocation scenarios.

There was one successful scenario for the North River watershed (Table 7.1). This scenario was developed under the assumption that TMDLs that have already been developed within the North River watershed will be met. This decreased the violation of the instantaneous standards to within our Stage 1 implementation goal; thus no additional reductions will be necessary for Stage 1 implementation. However, because full implementation of TMDLs on North River tributaries is not yet complete and may not be attained, watershed stakeholders may wish to select alternative or additional implementation milestones during the development of the TMDL IP in order to speed implementation and attainment of water quality goals in the North River itself. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the Stage 1 fecal coliform loads are presented graphically in Figure 7.1.

Table 7.1. Allocation scenario for Stage 1 TMDL implementation for the North River TMDL watershed.

Single Sample Standard % Violation	% Reduction Required					
	Cattle DD	Cropland	Pasture	Wildlife DD	Straight Pipes	All Residential PLS
5	0	0	0	0	0	0

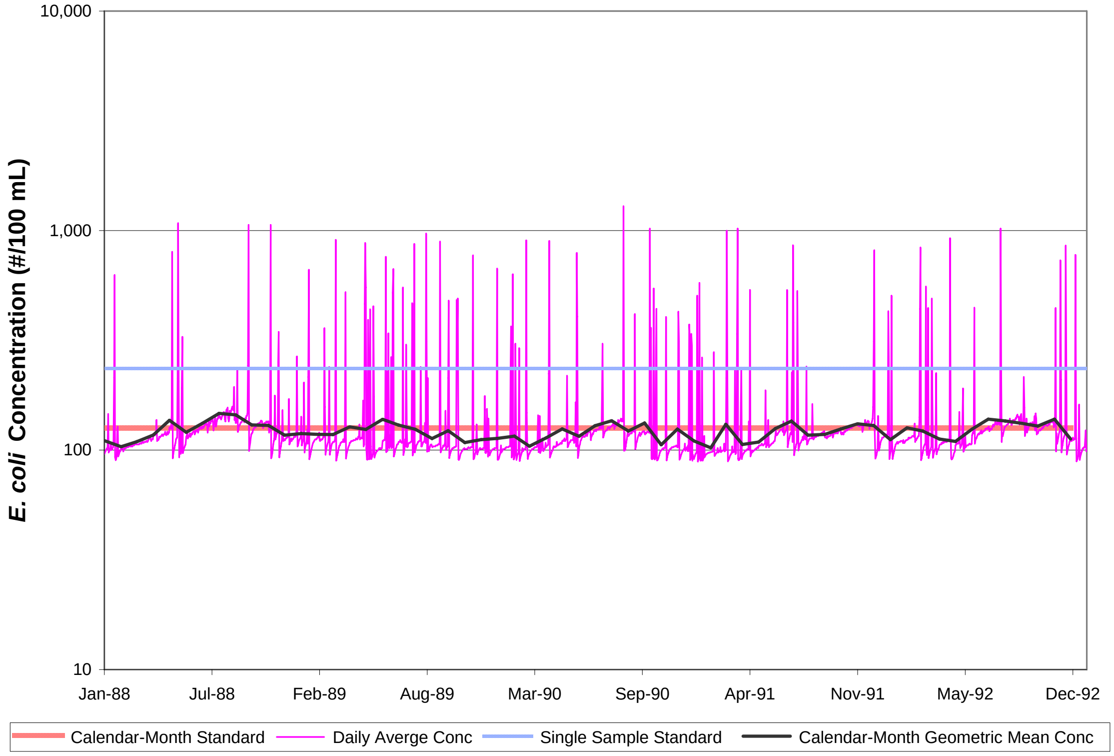

Figure 7.1. Calendar-month geometric mean standard, single sample standard, and Stage 1 TMDL implementation scenario for the North River watershed.

7.3. Link to ongoing Restoration Efforts

Implementation of this TMDL will contribute to on-going water quality improvement efforts aimed at restoring water quality in the Chesapeake Bay. Several BMPs known to be effective in controlling bacteria have been identified for implementation as part of the Tributary Strategy for the Shenandoah and Potomac River Basins. For example, management of on-site waste management systems, management of livestock and manure, and pet waste management are among the components of the strategy described under nonpoint source implementation mechanisms (VASNR, 1996). Up-to-date information on the tributary strategy can be found at the tributary strategy web site under http://www.snr.state.va.us/Initiatives/TributaryStrategies/shenandoah.cfm.

Additionally, the success of this TMDL will rely heavily on the current implementation efforts in the contributing areas with previously developed

TMDLs. Links to these previously developed TMDL plans and corresponding implementation plans are presented in Table 7.2.

Table 7.2. Previously Developed TMDLs and Implementation Plans for the Contributing Areas.

Watershed	TMDL Report[1]	Implementation Plan
Dry River	dryr01.pdf	http://www.deq.virginia.gov/tmdl/implans/nriverip.pdf
Muddy Creek	muddyfe.pdf	
Mill Creek	millcr.pdf	
Pleasant Run	pleasant.pdf	
Mossy Creek & Long Glade	mossglad.pdf	n/a[2]
Beaver Creek	beaver.pdf[3]	n/a[2]
Middle River	middle.pdf	n/a[2]
Christians Creek	chrstnfc.pdf	n/a[2]
Naked Creek	nkdcreek.pdf	n/a[2]
Cooks Creek	cooksfd1.pdf	n/a[2]
Blacks Run	blacksfc.pdf	n/a[2]

[1] At http://www.deq.virginia.gov/tmdl/apptmdls/shenrvr/ unless otherwise noted; the site to locate approved TMDL reports is: http://gisweb.deq.virginia.gov/tmdlapp/tmdl_report_search.cfm

[2] not applicable – an implementation plan has not yet been developed for these watersheds

[3] At publication time, this document was located at http://www.deq.virginia.gov/tmdl/drftmdls/ - however, it has been approved and will soon be moved to the same location as the other reports

7.4. Reasonable Assurance for Implementation

7.4.1. Follow-up Monitoring

Following the development of the TMDL, the Department of Environmental Quality (DEQ) will make every effort to continue to monitor the impaired stream in accordance with its ambient monitoring program. DEQ's Ambient Watershed Monitoring Plan for conventional pollutants calls for watershed monitoring to take place on a rotating basis, bi-monthly for two consecutive years of a six-year cycle. In accordance with DEQ Guidance Memo No. 03-2004, during periods of reduced resources, monitoring can temporarily discontinue until the TMDL staff determines that implementation measures to address the source(s) of impairments are being installed. Monitoring can resume at the start of the following fiscal year, next scheduled monitoring station rotation, or where deemed necessary by the regional office or TMDL staff, as a new special study.

The purpose, location, parameters, frequency, and duration of the monitoring will be determined by the DEQ staff, in cooperation with DCR staff, the Implementation Plan Steering Committee and local stakeholders. Whenever possible, the location of the follow-up monitoring station(s) will be the same as the listing station. At a minimum, the monitoring station must be representative of the original impaired segment. The details of the follow-up monitoring will be outlined in the Annual Water Monitoring Plan prepared by each DEQ Regional Office. Other agency personnel, watershed stakeholders, etc. may provide input on the Annual Water Monitoring Plan. These recommendations must be made to the DEQ regional TMDL coordinator by September 30 of each year.

DEQ staff, in cooperation with DCR staff, the Implementation Plan Steering Committee and local stakeholders, will continue to use data from the ambient monitoring stations to evaluate reductions in pollutants ("water quality milestones" as established in the IP), the effectiveness of the TMDL in attaining and maintaining water quality standards, and the success of implementation efforts. Recommendations may then be made, when necessary, to target implementation efforts in specific areas and continue or discontinue monitoring at follow-up stations.

In some cases, watersheds will require monitoring above and beyond what is included in DEQ's standard monitoring plan. Ancillary monitoring by citizens, watershed groups, local government, or universities is an option that may be used in such cases. An effort should be made to ensure that ancillary monitoring follows established QA/QC guidelines in order to maximize compatibility with DEQ monitoring data. In instances where citizens' monitoring data is not available and additional monitoring is needed to assess the effectiveness of targeting efforts, TMDL staff may request of the monitoring managers in each regional office an increase in the number of stations or monitor existing stations at a higher frequency in the watershed. The additional monitoring beyond the original bimonthly single station monitoring will be contingent on staff resources and available laboratory budget. More information on citizen monitoring in Virginia and QA/QC guidelines is available at http://www.deq.virginia.gov/cmonitor/.

To demonstrate that the watershed is meeting water quality standards in watersheds where corrective actions have taken place (whether or not a TMDL or TMDL Implementation Plan has been completed), DEQ must meet the minimum data requirements from the original listing station or a station representative of the originally listed segment. The minimum data requirement for conventional pollutants (bacteria, dissolved oxygen, etc) is bimonthly monitoring for two consecutive years. For biological monitoring, the minimum requirement is two consecutive samples (one in the spring and one in the fall) in a one year period.

7.4.2. Regulatory Framework

While section 303(d) of the Clean Water Act and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. EPA also requires that all new or revised National Pollutant Discharge Elimination System (NPDES) permits must be consistent with the TMDL WLA pursuant to 40 CFR §122.44 (d)(1)(vii)(B). All such permits should be submitted to EPA for review.

Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (the "Act") directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

For the implementation of the WLA component of the TMDL, the Commonwealth intends to utilize the Virginia NPDES (VPDES) program, which typically includes consideration of the WQMIRA requirements during the permitting process. Requirements of the permit process should not be duplicated in the TMDL process, and with the exception of stormwater related permits, permitted sources are not usually addressed during the development of a TMDL implementation plan.

For the implementation of the TMDL's LA component, a TMDL implementation plan addressing at a minimum the WQMIRA requirements will be developed. An exception are the municipal separate storm sewer systems (MS4s) which are both covered by NPDES permits and expected to be included in TMDL implementation plans, as described in the stormwater permit section below.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan. Regional and local offices of DEQ, DCR, and other cooperating agencies are technical resources to assist in this endeavor.

In response to a Memorandum of Understanding (MOU) between EPA and DEQ, DEQ also submitted a draft Continuous Planning Process to EPA in which DEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

DEQ staff will present both EPA-approved TMDLs and TMDL implementation plans to the State Water Control Board for inclusion in the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e) and Virginia's Public Participation Guidelines for Water Quality Management Planning.

DEQ staff will also request that the SWCB adopt TMDL WLAs as part of the Water Quality Management Planning Regulation (9VAC 25-720), except in those cases when permit limitations are equivalent to numeric criteria contained in the Virginia Water Quality Standards, such as is the case for bacteria. This regulatory action is in accordance with §2.2-4006A.4.c and §2.2-4006B of the Code of Virginia. SWCB actions relating to water quality management planning are described in the public participation guidelines referenced above and can be found on DEQ's web site under http://www.deq.state.va.us/tmdl/pdf/ppp.pdf.

7.4.3. Stormwater Permits

DEQ and DCR coordinate separate State programs that regulate the management of pollutants carried by storm water runoff. DEQ regulates storm water discharges associated with "industrial activities", while DCR regulates storm water discharges from construction sites and from municipal separate storm sewer systems (MS4s).

EPA approved DCR's VPDES storm water program on December 30, 2004. DCR's regulations became effective on January 29, 2005. DEQ is no longer the regulatory agency responsible for administration and enforcement of the VPDES MS4 and construction storm water permitting programs. More information is available on DCR's web site through the following link: http://www.dcr.virginia.gov/sw/vsmp.

It is the intention of the Commonwealth that the TMDL will be implemented using existing regulations and programs. One of these regulations is DCR's Virginia Stormwater Management Program (VSMP) Permit Regulation (4 VAC 50-60-10 et. seq). Section 4VAC 50-60-380 describes the requirements for stormwater discharges. Also, federal regulations state in 40 CFR §122.44(k) that NPDES permit conditions may consist of "Best management practices to control or abate the discharge of pollutants when:…(2) Numeric effluent limitations are infeasible,…".

Part of the North River TMDL watershed is covered by a Phase II VSMP permit (VAR040054) for the small municipal separate storm sewer system (MS4) owned by the town of Bridgewater. This permit was issued on March 7, 2003 and the coverage of the permit is from December 9, 2002 to December 9, 2007. The permit states, under Part II.A., that the "permittee must develop, implement, and enforce a storm water management program designed to reduce the discharge of pollutants from the MS4 to the maximum extent practicable (MEP), to protect water quality, and to satisfy the appropriate water quality requirements of the Clean Water Act and the State Water Control Law."

The permit also contains a TMDL clause that states: "If a TMDL is approved for any waterbody into which the small MS4 discharges, the Board will review the TMDL to determine whether the TMDL includes requirements for control of storm water discharges. If discharges from the MS4 are not meeting the TMDL allocations, the Board will notify the permittee of that finding and may require that the Storm Water Management Program required in Part II be modified to implement the TMDL within a timeframe consistent with the TMDL." ("Board" means the Soil and Water Conservation Board)

For MS4/VSMP general permits, the Commonwealth expects the permittee to specifically address the TMDL wasteload allocations for stormwater through the implementation of programmatic BMPs. BMP effectiveness would be determined through ambient in-stream monitoring. This is in accordance with recent EPA guidance (EPA Memorandum on TMDLs and Stormwater Permits, dated November 22, 2002). If future monitoring indicates no improvement in stream water quality, the permit could require the MS4 to expand or better tailor its stormwater management program to achieve the TMDL wasteload allocation. However, only failing to implement the programmatic BMPs identified in the modified stormwater management program would be considered a violation of the permit. DEQ acknowledges that it may not be possible to meet the existing water quality standard because of the wildlife issue associated with a number of bacteria TMDLs (see section 7.4.5 below). At some future time, it may therefore become necessary to investigate the stream's use designation and adjust the water quality criteria through a Use Attainability Analysis. Any changes to the TMDL resulting from water quality standards change on North River would be reflected in the permit.

Wasteload allocations for stormwater discharges from storm sewer systems covered by a MS4 permit will be addressed in TMDL implementation plans. An implementation plan will identify types of corrective actions and strategies to obtain the wasteload allocation for the pollutant causing the water quality impairment. Permittees need to participate in the development of TMDL implementation plans since recommendations from the process may result in modifications to the stormwater management plan in order to meet the TMDL.

Additional information on Virginia's Stormwater Management program and a downloadable menu of Best Management Practices and Measurable Goals Guidance can be found at http://www.dcr.virginia.gov/sw/stormwat.htm.

7.4.4. Implementation Funding Sources

Cooperating agencies, organizations and stakeholders must identify potential funding sources available for implementation during the development of the implementation plan in accordance with the "Virginia Guidance Manual for Total Maximum Daily Load Implementation Plans". Potential sources for implementation may include the U.S. Department of Agriculture's Conservation

Reserve Enhancement and Environmental Quality Incentive Programs, EPA Section 319 funds, the Virginia State Revolving Loan Program, Virginia Agricultural Best Management Practices Cost-Share Programs, the Virginia Water Quality Improvement Fund, tax credits and landowner contributions. The TMDL Implementation Plan Guidance Manual contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

7.4.5. Attainability of Primary Contact Recreation Use

In some streams for which TMDLs have been developed, water quality modeling indicates that even after removal of all bacteria sources (other than wildlife), the stream will not attain standards under all flow regimes at all times. These streams may not be able to attain standards without some reduction in wildlife load.

With respect to these potential reductions in bacteria loads attributed to wildlife, Virginia and EPA are not proposing the elimination of wildlife to allow for the attainment of water quality standards. However, if bacteria levels remain high and localized overabundant populations of wildlife are identified as the source, then measures to reduce such populations may be an option if undertaken in consultation with the Department of Game and Inland Fisheries (DGIF) or the United States Fish and Wildlife Service (USFWS). Additional information on DGIF's wildlife programs can be found at http://www.dgif.virginia.gov/hunting/va_game_wildlife/. While managing such overpopulations of wildlife remains as an option to local stakeholders, the reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL.

To address the overall issue of attainability of the primary contact criteria, Virginia proposed during its latest triennial water quality standards review a new "secondary contact" category for protecting the recreational use in state waters. On March 25, 2003, the Virginia State Water Control Board adopted criteria for "secondary contact recreation" which means "a water-based form of recreation, the practice of which has a low probability for total body immersion or ingestion of waters (examples include but are not limited to wading, boating and fishing)". These new criteria became effective on February 12, 2004 and can be found at http://www.deq.virginia.gov/wqs/rule.html.

In order for the new criteria to apply to a specific stream segment, the primary contact recreational use must be removed. To remove a designated use, the state must demonstrate 1) that the use is not an existing use, 2) that downstream uses are protected, and 3) that the source of contamination is natural and uncontrollable by effluent limitations and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10). This and other information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted as amendments to the water quality standards regulations. Watershed stakeholders and EPA will be able to provide comment during this process. Additional information can be obtained at http://www.deq.virginia.gov/wqs/WQS03AUG.pdf

The process to address potentially unattainable reductions based on the above is as follows: First is the development of a stage 1 scenario such as that presented previously in this chapter. The pollutant reductions in the stage 1 scenario are targeted primarily at the controllable, anthropogenic bacteria sources identified in the TMDL, setting aside control strategies for wildlife except for cases of nuisance populations. During the implementation of the stage 1 scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described in Section 7.1 above. DEQ will re-assess water quality in the stream during and subsequent to the implementation of the stage 1 scenario to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct. If water quality standards are not being met, and no additional cost-effective and reasonable best management practices can be identified, a UAA may be initiated with the goal of re-designating the stream for secondary contact recreation.

CHAPTER 8: PUBLIC PARTICIPATION

Public participation was elicited at every stage of TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. In October of 2004, members of the Virginia Tech TMDL group traveled to Augusta and Rockingham Counties to become acquainted with the watershed. Personnel from Virginia Tech contacted stakeholders via telephone to acquire their input.

The first public meeting was held on September 23, 2004 at the John Wayland Elementary School in Bridgewater, Virginia to inform the stakeholders of TMDL development process. Approximately 18 people attended the meeting.

Two local steering committee meetings were held after the first public meeting. This committee consisted of a group of interested stakeholders for the watershed. During the first local steering committee meeting on October 14, 2004 at the DEQ office in Harrisonburg, the committee members provided feedback on and refinement of the human and animal numbers used in modeling. During the second meeting on September 28, 2005, also located at the DEQ office, the committee members provided feedback on the hydrology and water quality calibrations, as well as the preliminary allocation scenarios. Eleven stakeholders attended the first meeting and six attended the second meeting. At each of these meetings, the attendees received a packet of information containing details on the topic of discussion.

The final public meeting was held on November 14, 2005 at the John Wayland Elementary School in Bridgewater, Virginia to present the draft TMDL report and solicit comments from stakeholders. Approximately 14 people attended the final meeting. Copies of the presentation materials and the executive summary of this report were distributed to the public at the meeting. The public comment period ended on December 14, 2005.

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APPENDIX A.
Glossary of Terms

Glossary of Terms

Allocation

That portion of a receiving water's loading capacity that is attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources.

Allocation Scenario

A proposed series of point and nonpoint source allocations (loadings from different sources), which are being considered to meet a water quality planning goal.

Background levels

Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering and dissolution.

BASINS (Better Assessment Science Integrating Point and Nonpoint Sources)

A computer-run tool that contains an assessment and planning component that allows users to organize and display geographic information for selected watersheds. It also contains a modeling component to examine impacts of pollutant loadings from point and nonpoint sources and to characterize the overall condition of specific watersheds.

Best Management Practices (BMP)

Methods, measures, or practices that are determined to be reasonable and cost-effective means for a land owner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.

Bacteria Source Tracking

A collection of scientific methods used to track sources of fecal coliform.

Calibration

The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.

Die-off (of fecal coliform)

Reduction in the fecal coliform population due to predation by other bacteria as well as by adverse environmental conditions (e.g., UV radiation, pH).

Direct nonpoint sources

Sources of pollution that are defined statutorily (by law) as nonpoint sources that are represented in the model as point source loadings due to limitations of the model. Examples include: direct deposits of fecal material to streams from livestock and wildlife.

E-911 digital data

Emergency response database prepared by the county that contains graphical data on road centerlines and buildings. The database contains approximate outlines of buildings, including dwellings and poultry houses.

Failing septic system

Septic systems in which drain fields have failed such that effluent (wastewater) that is supposed to percolate into the soil, now rises to the surface and ponds on the surface where it can flow over the soil surface to streams or contribute pollutants to the surface where they can be lost during storm runoff events.

Fecal coliform

A type of bacteria found in the feces of various warm-blooded animals that is used as indicator of the possible presence of pathogenic (disease causing) organisms.

Geometric mean

The geometric mean is simply the nth root of the product of n values. Using the geometric mean, lessens the significance of a few extreme values (extremely high or low values). In practical terms, this means that if you have just a few bad samples, their weight is lessened.

Mathematically the geometric mean, $\bar{x}_g$, is expressed as:

$$\bar{x}_g = \sqrt[n]{x_1 \cdot x_2 \cdot x_3 \ldots \cdot x_n}$$

where n is the number of samples, and x_i is the value of sample i.

HSPF (Hydrological Simulation Program-Fortran)

A computer-based model that calculates runoff, sediment yield, and fate and transport of various pollutants to the stream. The model was developed under the direction of the U.S. Environmental Protection Agency (EPA).

Hydrology

The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

Instantaneous criterion

The instantaneous criterion or instantaneous water quality standard is the value of the water quality standard that should not be exceeded at any time. For example, the Virginia instantaneous water quality standard for fecal coliform is 1,000 cfu/100 mL. If this value is exceeded at any time, the water body is in violation of the state water quality standard.

Load allocation (LA)

The portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background.

Margin of Safety (MOS)

A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody. The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models). The MOS may also be assigned explicitly, as was done in this study, to ensure that the water quality standard is not violated.

Model

Mathematical representation of hydrologic and water quality processes. Effects of Land use, slope, soil characteristics, and management practices are included.

Nonpoint source

Pollution that is not released through pipes but rather originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

Pathogen

Disease-causing agent, especially microorganisms such as bacteria, protozoa, and viruses.

Point source

Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

Pollution

Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.

Reach

Segment of a stream or river.

Runoff

That part of rainfall or snowmelt that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.

Septic system

An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives liquid and solid wastes from a residence or business and a drainfield or subsurface absorption system consisting of a series of tile or percolation lines for disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.

Simulation

The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.

Straight pipe

Delivers wastewater directly from a building, e.g., house, milking parlor, to a stream, pond, lake, or river.

Total Maximum Daily Load (TMDL)

The sum of the individual wasteload allocations (WLA's) for point sources, load allocations (LA's) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

Urban Runoff

Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.

Validation (of a model)

Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical process under investigation.

Wasteload allocation (WLA)

The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation.

Water quality standard

Law or regulation that consists of the beneficial designated use or uses of a water body, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular water body, and an anti-degradation statement.

Watershed

A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

For more definitions, see the Virginia Cooperative Extension publications available online:

Glossary of Water-Related Terms. Publication 442-758.
http://www.ext.vt.edu/pubs/bse/442-758/442-758.html

and

TMDLs (Total Maximum Daily Loads) - Terms and Definitions. Publication 442-550.
http://www.ext.vt.edu/pubs/bse/442-550/442-550.html

APPENDIX B.
Sample Calculation of Cattle
(Sub-Watershed NR-03)

Sample Calculation: Distribution of Cattle

(Sub-watershed NR-03 during January)

(Note: Due to rounding, the numbers may not add up.)

There are 199 beef cows in sub-watershed 03.

1. During January, beef cattle are confined 40% of the time (Table 4.5).
   Beef cattle in confinement = 199 * (40%) = 79.6
2. When not confined, cattle are on the pasture or in the stream.
   Beef cattle on pasture and in the stream = (199-79.6) = 119.4
3. Eight percent of the pasture acreage has stream access. Hence beef cattle with stream access are calculated as:
   Beef cattle on pastures with stream access = 119.4 * (8%) = 9.6
4. Beef cattle in and around the stream are calculated using the numbers in Step 3 and the number of hours cattle spend in the stream in January (Table 4.5) as:
   Beef cattle in and around streams = 9.6 * (0.5/24) = 0.20
5. Number of cattle defecating in the stream is calculated by multiplying the number of cattle in and around the stream by 30% (Section 0)
   Beef cattle defecating in streams = 0.20 * (30%) = 0.06
6. After calculating the number of cattle defecating in the stream, the number of cattle defecating on the pasture is calculated by subtracting the number of cattle defecating in the stream (Step 5) from number of cattle in pasture and stream (Step 2).
   Beef cattle defecating on pasture = (119.4 - 0.06) = 119.3

Now, obviously there is not 6/100th of a cow standing and defecating in the stream. This number represents the fraction of fecal coliform produced in one day by one cow that will be deposited in the stream.

APPENDIX C.
Die-off Fecal Coliform During Storage

Die-off of Fecal Coliform During Storage

The following procedure was used to calculate amount of fecal coliform produced in confinement in dairy manure applied to cropland and pasture. All calculations were performed on spreadsheet for each sub watershed with dairy operations in a watershed.

1. It was determined from a producer survey in Rockingham County that 15% of the dairy farms had dairy manure storage for less than 30 days; 10% of the dairy farms had storage capacities of 60 days, while the remaining operations had 180-day storage capacity. Using a decay rate of 0.375 for liquid dairy manure, the die-off of fecal coliform in different storage capacities at the ends of the respective storage periods were calculated using Eq. [5.1]. Based on the fractions of different storage capacities, a weighted average die-off was calculated for all dairy manure.
2. Based on fecal coliform die-off, the surviving fraction of fecal coliform at the end of storage period was estimated to be 0.0078 in dairy manure.
3. The annual production of fecal coliform based on 'as-excreted' values was calculated for dairy manure.
4. The annual fecal coliform production from dairy manure was multiplied by the fraction of surviving fecal coliform to obtain the amount of fecal coliform that was available for land application on annual basis. For monthly application, the annual figure was multiplied by the fraction of dairy applied during that month based on the application schedule given in Table 4.8.

APPENDIX D.
Weather Data Preparation

Weather Data Preparation

A weather data file for providing the weather data inputs into the HSPF Model was created for the period using WDMUtil. Raw data required for creating the weather data file included hourly precipitation (in.), average daily temperatures (maximum, minimum, and dew point) (°F), average daily wind speed (mi./h), total daily solar radiation (langleys), and percent sun. The primary data source for most parameters was the National Climatic Data Center's (NCDC) Cooperative Weather Station at Dale Enterprise, Rockingham Co., Virginia; data from three other NCDC stations were also used. Locations and data periods from the stations used are listed in Table D-1. Daily solar radiation data was generated using WDMUtil. The raw data required varying amounts of preprocessing prior to input into WDMUtil or within WDMUtil to obtain the following hourly values: precipitation (PREC), air temperature (ATEM), dew point temperature (DEWP), solar radiation (SOLR), wind speed (WIND), potential evapotranspiration (PEVT), potential evaporation (EVAP), and cloud cover (CLOU). The final WDM file contained the above hourly values as well as the raw data. Weather data in the variable length format were obtained from the NCDC's weather stations in Dale Enterprise, VA (Lat./Long. 38.5N/78.9W, elevation 1400 ft); Lynchburg Airport, VA (Lat./Long. 37.3N/79.2W, elevation 940 ft); and Elkins Airport, WV (Lat./Long. 38.9N/79.9W, elevation 1948 ft). While deciding on the period of record for the weather WDM file, availability of flow and water quality data was considered in addition to the availability and quality of weather data.

Table D.1. Meteorological data sources.

Type of Data	Location	Source	Recording Frequency	Period of Record	Latitude Longitude
Rainfall (in)	Dale Enterprise	NCDC	1 Hour 1 Day	1/1/73 - present 9/1/48 - present	38°10’52” 79°05’25”
Min Air Temp (°F)	Staunton Sewage Treatment Plant	NCDC	1 Day	8/1/48 - present	38°10’52” 79°05’25”
Max Air Temp (°F)	Staunton Sewage Treatment Plant	NCDC	1 Day	8/1/48 - present	38°10’52” 79°05’25”
Min Air Temp (°F)	Dale Enterprise	NCDC	1 Day	1/1/48 - present	38°27’19” 78°56’07”
Max Air Temp (°F)	Dale Enterprise	NCDC	1 Day	1/1/48 - present	38°27’19” 78°56’07”
Cloud Cover (%)	Lynchburg Regional Airport	NCDC	1 Day	1/1/65 - 7/31/96	37°20’15” 79°12’24”
Dew Point Temp (°F)	Elkins Airport, WV	NCDC	1 Day	1/1/48 - present	37°20’15” 79°12’24”
Wind Speed (360° and knots)	Elkins-Randolph Elkins WV	NCDC	1 Day	1/1/84 - present	38°53’07” 79°51’10”

APPENDIX E.
HSPF Parameters that Vary by Month or Land Use

Table E1. PWAT-PARM2 parameters varying by land use and sub-watershed.

Land Use	Parameter	Sub-watershed Number										
		1	2	3	4	5	6	7	8	9	10	11
Crop	INFILT	0.51	0.13	0.01	0.05	0.01	0.12	0.12	0.12	0.04	0.04	0.04
	LSUR	404	383	398	387	417	377	381	359	418	380	442
	SLSUR	0.055	0.065	0.058	0.063	0.049	0.068	0.066	0.076	0.048	0.066	0.037
Forest	INFILT	0.16	0.05	0.01	0.02	0.03	0.13	0.14	0.01	0.27	0.08	0.28
	LSUR	347	332	305	335	344	294	215	136	264	189	413
	SLSUR	0.081	0.089	0.101	0.087	0.083	0.106	0.143	0.18	0.12	0.155	0.051
HDR	INFILT	n/a	n/a	n/a	n/a	0.01	0.12	0.14	n/a	0.19	0.01	0.01
	LSUR	n/a	n/a	n/a	n/a	410	422	402	n/a	388	379	468
	SLSUR	n/a	n/a	n/a	n/a	0.052	0.047	0.056	n/a	0.062	0.067	0.025
LDR	INFILT	0.14	0.01	0.01	0.14	0.01	0.07	0.12	0.14	0.07	0.1	0.47
	LSUR	494	452	416	366	434	398	353	319	342	398	418
	SLSUR	0.013	0.032	0.049	0.072	0.041	0.058	0.079	0.095	0.084	0.058	0.048
Pasture	INFILT	0.1	0.06	0.01	0.01	0.01	0.11	0.1	0.1	0.07	0.02	0.01
	LSUR	409	392	365	391	377	359	347	287	367	326	397
	SLSUR	0.052	0.061	0.073	0.061	0.067	0.075	0.081	0.109	0.072	0.091	0.058

Table E1. PWAT-PARM2 parameters varying by land use and sub-watershed. (continued)

Land Use	Parameter	Sub-watershed Number											
		12	13	14	15	17	18	19	20	21	22	23	Ext.[a]
Crop	INFILT	0.06	0.15	0.15	0.15	0.13	0.09	0.07	0.14	0.01	0.09	0.18	0.09
	LSUR	437	349	373	452	469	425	400	404	152	100	492	382
	SLSUR	0.039	0.081	0.069	0.032	0.025	0.045	0.057	0.055	0.172	0.284	0.014	0.07
Forest	INFILT	0.11	0.07	0.25	0.14	0.08	0.08	0.06	0.08	0.02	0.08	0.41	0.05
	LSUR	281	106	391	326	380	295	110	145	100	100	496	100
	SLSUR	0.112	0.194	0.061	0.091	0.066	0.106	0.192	0.176	0.362	0.344	0.012	0.25
HDR	INFILT	0.03	0.13	0.14	0.23	0.14	0.05	0.06	0.11	0.02	0.05	0.39	0.03
	LSUR	480	407	357	503	471	344	438	374	100	323	502	378
	SLSUR	0.02	0.054	0.077	0.009	0.024	0.083	0.039	0.069	0.197	0.092	0.009	0.07
LDR	INFILT	0.06	0.14	0.14	0.15	0.12	0.06	0.03	0.13	0.12	0.01	n/a	0.05
	LSUR	468	353	321	488	463	413	401	416	385	210	n/a	369
	SLSUR	0.025	0.079	0.094	0.015	0.027	0.051	0.056	0.049	0.064	0.145	n/a	0.07
Pasture	INFILT	0.03	0.13	0.15	0.18	0.12	0.08	0.08	0.12	0.01	0.1	0.14	0.08
	LSUR	415	317	370	400	462	366	369	367	100	100	482	344
	SLSUR	0.05	0.096	0.071	0.057	0.028	0.072	0.071	0.072	0.357	0.33	0.018	0.08

n/a = not applicable, no land use of this type in this sub-watershed
[a]Ext. = external watersheds = watersheds with previously developed TMDLs

Table E2. MON-INTERCEP (monthly CEPSC) – Monthly Interception Storage.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Forest	0.1	0.1	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.1	0.1
HDR	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
LDR	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Pasture	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Crop	0.05	0.05	0.05	0.05	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15

Table E3. MON-UZSN – Monthly Upper Zone Nominal Storage.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Forest	0.1	0.1	0.1	0.2	0.3	0.5	0.5	0.5	0.5	0.4	0.1	0.1
HDR	0.05	0.05	0.07	0.07	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.05
LDR	0.05	0.05	0.07	0.07	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.05
Pasture	0.1	0.1	0.2	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.1
Crop	0.05	0.05	0.1	0.15	0.1	0.4	0.4	0.4	0.4	0.4	0.15	0.05

Table E4. MON-LZETP – Monthly Lower Zone Evapotranspiration Parameter.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Forest	0.15	0.15	0.25	0.3	0.35	0.6	0.6	0.6	0.6	0.45	0.25	0.15
HDR	0.1	0.1	0.1	0.15	0.25	0.25	0.25	0.25	0.25	0.15	0.1	0.1
LDR	0.1	0.1	0.1	0.15	0.25	0.25	0.25	0.25	0.25	0.15	0.1	0.1
Pasture	0.1	0.1	0.15	0.25	0.35	0.4	0.4	0.4	0.4	0.25	0.15	0.1
Crop	0.1	0.1	0.1	0.1	0.25	0.5	0.5	0.5	0.5	0.25	0.1	0.1

Table E5. MON-ACCUM Table – Monthly accumulation rate of bacteria on the soil surface (cfu/ac/day).

Sub-watershed	Land Use	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	Crop	2.80E+07	1.40E+09	6.40E+09	5.30E+09	1.30E+09	2.80E+07	2.80E+07	2.80E+07	2.80E+07	2.00E+09	2.00E+09	2.80E+07
1	Pasture	1.80E+09	2.00E+09	2.80E+09	2.80E+09	2.80E+09	2.80E+09	2.80E+09	2.90E+09	2.90E+09	2.40E+09	2.50E+09	1.80E+09
1	LDR	8.50E+10	8.50E+10	8.50E+10	8.50E+10	8.50E+10	8.50E+10	8.50E+10	8.50E+10	8.50E+10	8.50E+10	8.50E+10	8.50E+10
1	Forest	2.70E+08	2.70E+08	2.70E+08	2.70E+08	2.70E+08	2.70E+08	2.70E+08	2.70E+08	2.70E+08	2.70E+08	2.70E+08	2.70E+08
2	Crop	2.60E+07	1.50E+09	6.70E+09	5.50E+09	1.40E+09	2.60E+07	2.60E+07	2.60E+07	2.60E+07	2.00E+09	2.10E+09	2.60E+07
2	Pasture	1.80E+09	1.90E+09	2.80E+09	2.80E+09	2.70E+09	2.80E+09	2.80E+09	2.80E+09	2.90E+09	2.40E+09	2.40E+09	1.80E+09
2	LDR	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11
2	Forest	5.70E+08	5.70E+08	4.50E+08	4.50E+08	4.50E+08	4.50E+08	4.50E+08	4.50E+08	5.70E+08	5.70E+08	5.70E+08	5.70E+08
3	Crop	1.80E+07	1.50E+09	7.00E+09	5.80E+09	1.40E+09	1.80E+07	1.80E+07	1.80E+07	1.80E+07	2.10E+09	2.20E+09	1.80E+07
3	Pasture	2.10E+09	2.40E+09	4.00E+09	3.80E+09	3.20E+09	3.20E+09	3.30E+09	3.30E+09	3.50E+09	3.10E+09	3.10E+09	2.00E+09
3	LDR	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10
3	Forest	5.60E+08	5.60E+08	4.20E+08	4.20E+08	4.20E+08	4.20E+08	4.20E+08	4.20E+08	5.60E+08	5.60E+08	5.60E+08	5.60E+08
4	Crop	2.30E+07	8.40E+08	3.80E+09	3.10E+09	7.70E+08	2.30E+07	2.30E+07	2.30E+07	2.30E+07	1.20E+09	1.20E+09	2.30E+07
4	Pasture	1.70E+09	2.00E+09	3.40E+09	3.20E+09	2.70E+09	2.80E+09	2.80E+09	2.80E+09	3.00E+09	2.60E+09	2.60E+09	1.70E+09
4	LDR	6.00E+11	6.00E+11	6.00E+11	6.00E+11	6.00E+11	6.00E+11	6.00E+11	6.00E+11	6.00E+11	6.00E+11	6.00E+11	6.00E+11
4	Forest	8.50E+07	8.50E+07	7.10E+07	7.10E+07	7.10E+07	7.10E+07	7.10E+07	7.10E+07	8.50E+07	8.50E+07	8.50E+07	8.50E+07
5	Crop	1.80E+07	5.60E+08	2.50E+09	2.10E+09	5.20E+08	1.80E+07	1.80E+07	1.80E+07	1.80E+07	4.00E+08	8.00E+08	1.80E+07
5	Pasture	4.70E+09	5.00E+09	7.70E+09	7.60E+09	7.00E+09	7.00E+09	7.00E+09	7.10E+09	7.40E+09	6.70E+09	6.80E+09	4.70E+09
5	LDR	3.10E+09	3.10E+09	3.10E+09	3.10E+09	3.10E+09	3.10E+09	3.10E+09	3.10E+09	3.10E+09	3.10E+09	3.10E+09	3.10E+09
5	HDR	4.90E+10	4.90E+10	4.90E+10	4.90E+10	4.90E+10	4.90E+10	4.90E+10	4.90E+10	4.90E+10	4.90E+10	4.90E+10	4.90E+10
5	Forest	7.40E+08	7.40E+08	5.20E+08	5.20E+08	5.20E+08	5.20E+08	5.20E+08	5.20E+08	7.40E+08	7.40E+08	7.40E+08	7.40E+08
6	Crop	1.80E+07	9.20E+08	4.10E+09	3.40E+09	8.40E+08	1.80E+07	1.80E+07	1.80E+07	1.80E+07	1.30E+09	1.30E+09	1.80E+07
6	Pasture	1.80E+09	2.30E+09	4.30E+09	4.10E+09	3.20E+09	3.20E+09	3.20E+09	3.30E+09	3.60E+09	3.10E+09	3.10E+09	1.80E+09
6	LDR	3.40E+09	3.40E+09	3.40E+09	3.40E+09	3.40E+09	3.40E+09	3.40E+09	3.40E+09	3.40E+09	3.40E+09	3.40E+09	3.40E+09
6	HDR	1.80E+09	1.80E+09	1.80E+09	1.80E+09	1.80E+09	1.80E+09	1.80E+09	1.80E+09	1.80E+09	1.80E+09	1.80E+09	1.80E+09
6	Forest	2.60E+08	2.60E+08	1.90E+08	1.90E+08	1.90E+08	1.90E+08	1.90E+08	1.90E+08	2.60E+08	2.60E+08	2.60E+08	2.60E+08
7	Crop	2.10E+07	8.30E+08	3.70E+09	3.10E+09	7.60E+08	2.10E+07	2.10E+07	2.10E+07	2.10E+07	9.30E+08	1.20E+09	2.10E+07
7	Pasture	4.00E+09	4.40E+09	8.30E+09	8.50E+09	7.70E+09	7.70E+09	7.70E+09	7.80E+09	8.10E+09	7.60E+09	7.30E+09	4.00E+09
7	LDR	1.70E+10	1.70E+10	1.70E+10	1.70E+10	1.70E+10	1.70E+10	1.70E+10	1.70E+10	1.70E+10	1.70E+10	1.70E+10	1.70E+10
7	Forest	1.90E+08	1.90E+08	1.50E+08	1.50E+08	1.50E+08	1.50E+08	1.50E+08	1.50E+08	1.90E+08	1.90E+08	1.90E+08	1.90E+08
8	Crop	3.40E+07	1.50E+09	6.60E+09	5.50E+09	1.30E+09	3.40E+07	3.40E+07	3.40E+07	3.40E+07	2.00E+09	2.10E+09	3.40E+07
8	Pasture	2.00E+09	2.10E+09	2.90E+09	2.90E+09	2.90E+09	2.90E+09	3.00E+09	3.00E+09	3.00E+09	2.60E+09	2.60E+09	1.90E+09
8	LDR	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10
8	Forest	6.40E+08	6.40E+08	6.40E+08	6.40E+08	6.40E+08	6.40E+08	6.40E+08	6.40E+08	6.40E+08	6.40E+08	6.40E+08	6.40E+08

Table E5. MON-ACCUM Table - Monthly accumulation rate of bacteria on the soil surface (cfu/ac/day). (continued)

Sub-watershed	Land Use	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
9	Crop	4.20E+07	1.30E+09	5.90E+09	4.90E+09	1.20E+09	4.20E+07	4.20E+07	4.20E+07	4.20E+07	1.80E+09	1.90E+09	4.20E+07
9	Pasture	1.90E+09	3.20E+09	8.20E+09	7.30E+09	3.90E+09	4.00E+09	4.00E+09	4.00E+09	5.20E+09	4.60E+09	4.80E+09	1.80E+09
9	LDR	4.70E+08	4.70E+08	4.70E+08	4.70E+08	4.70E+08	4.70E+08	4.70E+08	4.70E+08	4.70E+08	4.70E+08	4.70E+08	4.70E+08
9	Forest	2.60E+08	2.60E+08	2.60E+08	2.60E+08	2.60E+08	2.60E+08	2.60E+08	2.60E+08	2.60E+08	2.60E+08	2.60E+08	2.60E+08
10	Crop	1.80E+07	1.40E+09	6.40E+09	5.30E+09	1.30E+09	1.80E+07	1.80E+07	1.80E+07	1.80E+07	1.90E+09	2.00E+09	1.80E+07
10	Pasture	2.50E+09	3.30E+09	6.80E+09	6.30E+09	4.50E+09	4.60E+09	4.60E+09	4.60E+09	5.30E+09	4.70E+09	4.80E+09	2.50E+09
10	LDR	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10
10	HDR	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09
10	Forest	4.90E+07	4.90E+07	4.90E+07	4.90E+07	4.90E+07	4.90E+07	4.90E+07	4.90E+07	4.90E+07	4.90E+07	4.90E+07	4.90E+07
11	Crop	2.90E+07	2.00E+09	8.80E+09	7.30E+09	1.80E+09	2.90E+07	2.90E+07	2.90E+07	2.90E+07	2.60E+09	2.80E+09	2.90E+07
11	Pasture	2.60E+09	3.10E+09	6.70E+09	6.70E+09	5.40E+09	5.50E+09	5.50E+09	5.50E+09	6.00E+09	5.50E+09	5.20E+09	2.60E+09
11	LDR	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08
11	HDR	4.40E+09	4.40E+09	4.40E+09	4.40E+09	4.40E+09	4.40E+09	4.40E+09	4.40E+09	4.40E+09	4.40E+09	4.40E+09	4.40E+09
11	Forest	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08
12	Crop	3.50E+07	1.50E+09	6.70E+09	5.50E+09	1.40E+09	3.50E+07	3.50E+07	3.50E+07	3.50E+07	2.10E+09	2.10E+09	3.50E+07
12	Pasture	1.80E+09	2.00E+09	2.80E+09	2.80E+09	2.80E+09	2.80E+09	2.80E+09	2.90E+09	2.90E+09	2.40E+09	2.50E+09	1.80E+09
12	LDR	9.60E+07	9.60E+07	9.60E+07	9.60E+07	9.60E+07	9.60E+07	9.60E+07	9.60E+07	9.60E+07	9.60E+07	9.60E+07	9.60E+07
12	HDR	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10
12	Forest	9.20E+07	9.20E+07	9.20E+07	9.20E+07	9.20E+07	9.20E+07	9.20E+07	9.20E+07	9.20E+07	9.20E+07	9.20E+07	9.20E+07
13	Crop	1.80E+07	8.10E+08	3.60E+09	3.00E+09	7.40E+08	1.80E+07	1.80E+07	1.80E+07	1.80E+07	8.80E+08	1.20E+09	1.80E+07
13	Pasture	8.20E+09	9.00E+09	1.50E+10	1.50E+10	1.30E+10	1.30E+10	1.30E+10	1.30E+10	1.40E+10	1.30E+10	1.30E+10	8.20E+09
13	LDR	6.40E+09	6.40E+09	6.40E+09	6.40E+09	6.40E+09	6.40E+09	6.40E+09	6.40E+09	6.40E+09	6.40E+09	6.40E+09	6.40E+09
13	Forest	1.20E+08	1.20E+08	9.40E+07	9.40E+07	9.40E+07	9.40E+07	9.40E+07	9.40E+07	1.20E+08	1.20E+08	1.20E+08	1.20E+08
14	Crop	1.70E+07	1.60E+09	7.30E+09	6.10E+09	1.50E+09	1.70E+07	1.70E+07	1.70E+07	1.70E+07	2.10E+09	2.30E+09	1.70E+07
14	Pasture	5.50E+09	6.10E+09	1.10E+10	1.10E+10	9.40E+09	9.40E+09	9.40E+09	9.50E+09	9.90E+09	9.40E+09	9.50E+09	5.50E+09
14	LDR	3.50E+10	3.50E+10	3.50E+10	3.50E+10	3.50E+10	3.50E+10	3.50E+10	3.50E+10	3.50E+10	3.50E+10	3.50E+10	3.50E+10
14	Forest	2.00E+08	2.00E+08	1.50E+08	1.50E+08	1.50E+08	1.50E+08	1.50E+08	1.50E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08
15	Crop	1.80E+07	5.60E+08	2.50E+09	2.10E+09	5.20E+08	1.80E+07	1.80E+07	1.80E+07	1.80E+07	4.00E+08	8.00E+08	1.80E+07
15	Pasture	1.00E+10	1.20E+10	2.70E+10	2.80E+10	2.30E+10	2.30E+10	2.30E+10	2.30E+10	2.50E+10	2.40E+10	2.30E+10	1.00E+10
15	LDR	2.10E+09	2.10E+09	2.10E+09	2.10E+09	2.10E+09	2.10E+09	2.10E+09	2.10E+09	2.10E+09	2.10E+09	2.10E+09	2.10E+09
15	Forest	4.80E+08	4.80E+08	3.30E+08	3.30E+08	3.30E+08	3.30E+08	3.30E+08	3.30E+08	4.80E+08	4.80E+08	4.80E+08	4.80E+08
17	Crop	1.80E+07	1.40E+09	6.30E+09	5.20E+09	1.30E+09	1.80E+07	1.80E+07	1.80E+07	1.80E+07	1.90E+09	2.00E+09	1.80E+07
17	Pasture	7.60E+08	1.40E+09	3.80E+09	3.20E+09	1.40E+09	1.40E+09	1.40E+09	1.40E+09	2.00E+09	2.00E+09	2.00E+09	7.60E+08
17	LDR	7.40E+09	7.40E+09	7.40E+09	7.40E+09	7.40E+09	7.40E+09	7.40E+09	7.40E+09	7.40E+09	7.40E+09	7.40E+09	7.40E+09
17	Forest	1.10E+08	1.10E+08	8.30E+07	8.30E+07	8.30E+07	8.30E+07	8.30E+07	8.30E+07	1.10E+08	1.10E+08	1.10E+08	1.10E+08

Table E5. MON-ACCUM Table – Monthly accumulation rate of bacteria on the soil surface (cfu/ac/day). (continued)

Sub-watershed	Land Use	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
18	Crop	1.80E+07	1.70E+09	7.70E+09	6.40E+09	1.60E+09	1.80E+07	1.80E+07	1.80E+07	1.80E+07	2.20E+09	2.40E+09	1.80E+07
18	Pasture	3.60E+09	4.10E+09	8.10E+09	8.10E+09	7.00E+09	7.00E+09	7.00E+09	7.10E+09	7.50E+09	7.00E+09	6.70E+09	3.60E+09
18	LDR	8.90E+09	8.90E+09	8.90E+09	8.90E+09	8.90E+09	8.90E+09	8.90E+09	8.90E+09	8.90E+09	8.90E+09	8.90E+09	8.90E+09
18	Forest	1.00E+08	1.00E+08	7.60E+07	7.60E+07	7.60E+07	7.60E+07	7.60E+07	7.60E+07	1.00E+08	1.00E+08	1.00E+08	1.00E+08
19	Crop	1.70E+07	9.30E+08	4.20E+09	3.50E+09	8.50E+08	1.70E+07	1.70E+07	1.70E+07	1.70E+07	1.20E+09	1.30E+09	1.70E+07
19	Pasture	3.60E+09	4.10E+09	6.70E+09	6.60E+09	5.70E+09	5.70E+09	5.70E+09	5.80E+09	6.10E+09	5.50E+09	5.50E+09	3.60E+09
19	LDR	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10
19	Forest	2.20E+07	2.20E+07	2.10E+07	2.10E+07	2.10E+07	2.10E+07	2.10E+07	2.10E+07	2.20E+07	2.20E+07	2.20E+07	2.20E+07
20	Crop	1.80E+07	1.00E+09	4.70E+09	3.90E+09	9.60E+08	1.80E+07	1.80E+07	1.80E+07	1.80E+07	1.40E+09	1.50E+09	1.80E+07
20	Pasture	3.10E+09	3.50E+09	6.40E+09	6.30E+09	5.40E+09	5.40E+09	5.40E+09	5.50E+09	5.80E+09	5.20E+09	5.20E+09	3.00E+09
20	LDR	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10
20	Forest	5.30E+07	5.30E+07	4.20E+07	4.20E+07	4.20E+07	4.20E+07	4.20E+07	4.20E+07	5.30E+07	5.30E+07	5.30E+07	5.30E+07
21	Crop	2.00E+07	2.00E+07	2.00E+07	2.00E+07	2.00E+07	2.00E+07	2.00E+07	2.00E+07	2.00E+07	2.00E+07	2.00E+07	2.00E+07
21	Pasture	7.20E+08	7.20E+08	7.20E+08	7.20E+08	7.20E+08	7.20E+08	7.20E+08	7.20E+08	7.20E+08	7.20E+08	7.20E+08	7.20E+08
21	LDR	3.40E+10	3.40E+10	3.40E+10	3.40E+10	3.40E+10	3.40E+10	3.40E+10	3.40E+10	3.40E+10	3.40E+10	3.40E+10	3.40E+10
21	Forest	3.90E+07	3.90E+07	3.20E+07	3.20E+07	3.20E+07	3.20E+07	3.20E+07	3.20E+07	3.90E+07	3.90E+07	3.90E+07	3.90E+07
22	Crop	3.20E+07	3.20E+07	3.20E+07	3.20E+07	3.20E+07	3.20E+07	3.20E+07	3.20E+07	3.20E+07	3.20E+07	3.20E+07	3.20E+07
22	Pasture	3.20E+07	3.20E+07	3.20E+07	3.20E+07	3.20E+07	3.20E+07	3.20E+07	3.20E+07	3.20E+07	3.20E+07	3.20E+07	3.20E+07
22	LDR	9.80E+09	9.80E+09	9.80E+09	9.80E+09	9.80E+09	9.80E+09	9.80E+09	9.80E+09	9.80E+09	9.80E+09	9.80E+09	9.80E+09
22	Forest	2.10E+07	2.10E+07	2.00E+07	2.00E+07	2.00E+07	2.00E+07	2.00E+07	2.00E+07	2.10E+07	2.10E+07	2.10E+07	2.10E+07
23	Crop	1.70E+07	2.50E+09	1.10E+10	9.30E+09	2.30E+09	1.70E+07	1.70E+07	1.70E+07	1.70E+07	3.40E+09	3.50E+09	1.70E+07
23	Pasture	1.80E+09	2.30E+09	4.30E+09	4.10E+09	3.20E+09	3.30E+09	3.30E+09	3.30E+09	3.70E+09	3.10E+09	3.10E+09	1.80E+09
23	Forest	3.90E+08	3.90E+08	2.60E+08	2.60E+08	2.60E+08	2.60E+08	2.60E+08	2.60E+08	3.90E+08	3.90E+08	3.90E+08	3.90E+08

Table E6. MON-SQOLIM Table - Monthly limit on surface accumulation of bacteria (cfu/ac).

Sub-watershed	Land Use	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	Crop	2.50E+08	1.30E+10	5.80E+10	4.80E+10	1.20E+10	2.50E+08	2.50E+08	2.50E+08	2.50E+08	1.80E+10	1.80E+10	2.50E+08
1	Pasture	1.70E+10	1.80E+10	2.50E+10	2.50E+10	2.50E+10	2.50E+10	2.60E+10	2.60E+10	2.60E+10	2.20E+10	2.20E+10	1.60E+10
1	LDR	7.60E+11	7.60E+11	7.60E+11	7.60E+11	7.60E+11	7.60E+11	7.60E+11	7.60E+11	7.60E+11	7.60E+11	7.60E+11	7.60E+11
1	Forest	2.40E+09	2.40E+09	2.40E+09	2.40E+09	2.40E+09	2.40E+09	2.40E+09	2.40E+09	2.40E+09	2.40E+09	2.40E+09	2.40E+09
2	Crop	2.40E+08	1.30E+10	6.00E+10	5.00E+10	1.20E+10	2.40E+08	2.40E+08	2.40E+08	2.40E+08	1.80E+10	1.90E+10	2.40E+08
2	Pasture	1.60E+10	1.70E+10	2.50E+10	2.50E+10	2.50E+10	2.50E+10	2.50E+10	2.50E+10	2.60E+10	2.20E+10	2.20E+10	1.60E+10
2	LDR	9.70E+11	9.70E+11	9.70E+11	9.70E+11	9.70E+11	9.70E+11	9.70E+11	9.70E+11	9.70E+11	9.70E+11	9.70E+11	9.70E+11
2	Forest	5.10E+09	5.10E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09	5.10E+09	5.10E+09	5.10E+09	5.10E+09
3	Crop	1.60E+08	1.40E+10	6.30E+10	5.20E+10	1.30E+10	1.60E+08	1.60E+08	1.60E+08	1.60E+08	1.90E+10	2.00E+10	1.60E+08
3	Pasture	1.90E+10	2.10E+10	3.60E+10	3.40E+10	2.90E+10	2.90E+10	2.90E+10	3.00E+10	3.20E+10	2.70E+10	2.80E+10	1.80E+10
3	LDR	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11
3	Forest	5.00E+09	5.00E+09	3.70E+09	3.70E+09	3.70E+09	3.70E+09	3.70E+09	3.70E+09	5.00E+09	5.00E+09	5.00E+09	5.00E+09
4	Crop	2.10E+08	7.60E+09	3.40E+10	2.80E+10	6.90E+09	2.10E+08	2.10E+08	2.10E+08	2.10E+08	1.00E+10	1.10E+10	2.10E+08
4	Pasture	1.50E+10	1.80E+10	3.00E+10	2.90E+10	2.50E+10	2.50E+10	2.50E+10	2.50E+10	2.70E+10	2.30E+10	2.40E+10	1.50E+10
4	LDR	5.40E+12	5.40E+12	5.40E+12	5.40E+12	5.40E+12	5.40E+12	5.40E+12	5.40E+12	5.40E+12	5.40E+12	5.40E+12	5.40E+12
4	Forest	7.70E+08	7.70E+08	6.40E+08	6.40E+08	6.40E+08	6.40E+08	6.40E+08	6.40E+08	7.70E+08	7.70E+08	7.70E+08	7.70E+08
5	Crop	1.60E+08	5.10E+09	2.30E+10	1.90E+10	4.60E+09	1.60E+08	1.60E+08	1.60E+08	1.60E+08	3.60E+09	7.20E+09	1.60E+08
5	Pasture	4.20E+10	4.50E+10	6.90E+10	6.80E+10	6.30E+10	6.30E+10	6.30E+10	6.40E+10	6.60E+10	6.00E+10	6.10E+10	4.20E+10
5	LDR	2.80E+10	2.80E+10	2.80E+10	2.80E+10	2.80E+10	2.80E+10	2.80E+10	2.80E+10	2.80E+10	2.80E+10	2.80E+10	2.80E+10
5	HDR	4.40E+11	4.40E+11	4.40E+11	4.40E+11	4.40E+11	4.40E+11	4.40E+11	4.40E+11	4.40E+11	4.40E+11	4.40E+11	4.40E+11
5	Forest	6.70E+09	6.70E+09	4.70E+09	4.70E+09	4.70E+09	4.70E+09	4.70E+09	4.70E+09	6.70E+09	6.70E+09	6.70E+09	6.70E+09
6	Crop	1.70E+08	8.30E+09	3.70E+10	3.10E+10	7.60E+09	1.70E+08	1.70E+08	1.70E+08	1.70E+08	1.10E+10	1.20E+10	1.70E+08
6	Pasture	1.70E+10	2.10E+10	3.90E+10	3.70E+10	2.80E+10	2.90E+10	2.90E+10	2.90E+10	3.30E+10	2.80E+10	2.80E+10	1.60E+10
6	LDR	3.10E+10	3.10E+10	3.10E+10	3.10E+10	3.10E+10	3.10E+10	3.10E+10	3.10E+10	3.10E+10	3.10E+10	3.10E+10	3.10E+10
6	HDR	1.70E+10	1.70E+10	1.70E+10	1.70E+10	1.70E+10	1.70E+10	1.70E+10	1.70E+10	1.70E+10	1.70E+10	1.70E+10	1.70E+10
6	Forest	2.30E+09	2.30E+09	1.70E+09	1.70E+09	1.70E+09	1.70E+09	1.70E+09	1.70E+09	2.30E+09	2.30E+09	2.30E+09	2.30E+09
7	Crop	1.80E+08	7.50E+09	3.30E+10	2.80E+10	6.80E+09	1.80E+08	1.80E+08	1.80E+08	1.80E+08	8.40E+09	1.10E+10	1.80E+08
7	Pasture	3.60E+10	3.90E+10	7.50E+10	7.60E+10	6.90E+10	7.00E+10	7.00E+10	7.00E+10	7.30E+10	6.80E+10	6.50E+10	3.60E+10
7	LDR	1.50E+11	1.50E+11	1.50E+11	1.50E+11	1.50E+11	1.50E+11	1.50E+11	1.50E+11	1.50E+11	1.50E+11	1.50E+11	1.50E+11
7	Forest	1.70E+09	1.70E+09	1.40E+09	1.40E+09	1.40E+09	1.40E+09	1.40E+09	1.40E+09	1.70E+09	1.70E+09	1.70E+09	1.70E+09
8	Crop	3.00E+08	1.30E+10	5.90E+10	4.90E+10	1.20E+10	3.00E+08	3.00E+08	3.00E+08	3.00E+08	1.80E+10	1.90E+10	3.00E+08
8	Pasture	1.80E+10	1.90E+10	2.60E+10	2.60E+10	2.60E+10	2.60E+10	2.70E+10	2.70E+10	2.70E+10	2.30E+10	2.30E+10	1.70E+10
8	LDR	1.00E+11	1.00E+11	1.00E+11	1.00E+11	1.00E+11	1.00E+11	1.00E+11	1.00E+11	1.00E+11	1.00E+11	1.00E+11	1.00E+11
8	Forest	5.70E+09	5.70E+09	5.70E+09	5.70E+09	5.70E+09	5.70E+09	5.70E+09	5.70E+09	5.70E+09	5.70E+09	5.70E+09	5.70E+09

Table E6. MON-SQOLIM Table - Monthly limit on surface accumulation of bacteria (cfu/ac). (continued)

Sub-watershed	Land Use	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
9	Crop	1.70E+08	1.30E+10	5.70E+10	4.70E+10	1.20E+10	1.70E+08	1.70E+08	1.70E+08	1.70E+08	1.70E+10	1.80E+10	1.70E+08
9	Pasture	2.30E+10	2.90E+10	6.10E+10	5.70E+10	4.10E+10	4.10E+10	4.10E+10	4.10E+10	4.70E+10	4.30E+10	4.30E+10	2.30E+10
9	LDR	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11
9	Forest	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10
10	Crop	4.40E+08	4.40E+08	4.40E+08	4.40E+08	4.40E+08	4.40E+08	4.40E+08	4.40E+08	4.40E+08	4.40E+08	4.40E+08	4.40E+08
10	Pasture	2.70E+08	1.80E+10	7.90E+10	6.60E+10	1.60E+10	2.70E+08	2.70E+08	2.70E+08	2.70E+08	2.30E+10	2.50E+10	2.70E+08
10	LDR	2.30E+10	2.80E+10	6.00E+10	6.00E+10	4.90E+10	4.90E+10	4.90E+10	4.90E+10	5.40E+10	4.90E+10	4.70E+10	2.30E+10
10	HDR	8.10E+09	8.10E+09	8.10E+09	8.10E+09	8.10E+09	8.10E+09	8.10E+09	8.10E+09	8.10E+09	8.10E+09	8.10E+09	8.10E+09
10	Forest	4.00E+10	4.00E+10	4.00E+10	4.00E+10	4.00E+10	4.00E+10	4.00E+10	4.00E+10	4.00E+10	4.00E+10	4.00E+10	4.00E+10
11	Crop	1.80E+09	1.80E+09	1.80E+09	1.80E+09	1.80E+09	1.80E+09	1.80E+09	1.80E+09	1.80E+09	1.80E+09	1.80E+09	1.80E+09
11	Pasture	3.10E+08	1.30E+10	6.00E+10	5.00E+10	1.20E+10	3.10E+08	3.10E+08	3.10E+08	3.10E+08	1.90E+10	1.90E+10	3.10E+08
11	LDR	1.70E+10	1.80E+10	2.50E+10	2.50E+10	2.50E+10	2.50E+10	2.60E+10	2.60E+10	2.60E+10	2.20E+10	2.20E+10	1.60E+10
11	HDR	8.60E+08	8.60E+08	8.60E+08	8.60E+08	8.60E+08	8.60E+08	8.60E+08	8.60E+08	8.60E+08	8.60E+08	8.60E+08	8.60E+08
11	Forest	9.20E+10	9.20E+10	9.20E+10	9.20E+10	9.20E+10	9.20E+10	9.20E+10	9.20E+10	9.20E+10	9.20E+10	9.20E+10	9.20E+10
12	Crop	8.30E+08	8.30E+08	8.30E+08	8.30E+08	8.30E+08	8.30E+08	8.30E+08	8.30E+08	8.30E+08	8.30E+08	8.30E+08	8.30E+08
12	Pasture	1.70E+08	7.30E+09	3.30E+10	2.70E+10	6.70E+09	1.70E+08	1.70E+08	1.70E+08	1.70E+08	8.00E+09	1.00E+10	1.70E+08
12	LDR	7.40E+10	8.10E+10	1.40E+11	1.40E+11	1.20E+11	1.20E+11	1.20E+11	1.20E+11	1.20E+11	1.20E+11	1.20E+11	7.30E+10
12	HDR	5.70E+10	5.70E+10	5.70E+10	5.70E+10	5.70E+10	5.70E+10	5.70E+10	5.70E+10	5.70E+10	5.70E+10	5.70E+10	5.70E+10
12	Forest	1.10E+09	1.10E+09	8.50E+08	8.50E+08	8.50E+08	8.50E+08	8.50E+08	8.50E+08	1.10E+09	1.10E+09	1.10E+09	1.10E+09
13	Crop	1.60E+08	1.50E+10	6.60E+10	5.50E+10	1.30E+10	1.60E+08	1.60E+08	1.60E+08	1.60E+08	1.90E+10	2.10E+10	1.60E+08
13	Pasture	5.00E+10	5.50E+10	9.80E+10	9.50E+10	8.40E+10	8.50E+10	8.50E+10	8.50E+10	8.90E+10	8.50E+10	8.60E+10	5.00E+10
13	LDR	3.20E+11	3.20E+11	3.20E+11	3.20E+11	3.20E+11	3.20E+11	3.20E+11	3.20E+11	3.20E+11	3.20E+11	3.20E+11	3.20E+11
13	Forest	1.80E+09	1.80E+09	1.40E+09	1.40E+09	1.40E+09	1.40E+09	1.40E+09	1.40E+09	1.80E+09	1.80E+09	1.80E+09	1.80E+09
14	Crop	1.70E+08	5.10E+09	2.30E+10	1.90E+10	4.60E+09	1.70E+08	1.70E+08	1.70E+08	1.70E+08	3.60E+09	7.20E+09	1.70E+08
14	Pasture	9.10E+10	1.10E+11	2.40E+11	2.50E+11	2.10E+11	2.10E+11	2.10E+11	2.10E+11	2.20E+11	2.20E+11	2.10E+11	9.10E+10
14	LDR	1.90E+10	1.90E+10	1.90E+10	1.90E+10	1.90E+10	1.90E+10	1.90E+10	1.90E+10	1.90E+10	1.90E+10	1.90E+10	1.90E+10
14	Forest	4.40E+09	4.40E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	4.40E+09	4.40E+09	4.40E+09	4.40E+09
15	Crop	1.60E+08	1.30E+10	5.60E+10	4.70E+10	1.10E+10	1.60E+08	1.60E+08	1.60E+08	1.60E+08	1.70E+10	1.80E+10	1.60E+08
15	Pasture	6.80E+09	1.30E+10	3.40E+10	2.90E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.80E+10	1.80E+10	1.80E+10	6.80E+09
15	LDR	6.70E+10	6.70E+10	6.70E+10	6.70E+10	6.70E+10	6.70E+10	6.70E+10	6.70E+10	6.70E+10	6.70E+10	6.70E+10	6.70E+10
15	Forest	1.00E+09	1.00E+09	7.50E+08	7.50E+08	7.50E+08	7.50E+08	7.50E+08	7.50E+08	1.00E+09	1.00E+09	1.00E+09	1.00E+09
17	Crop	1.70E+08	1.30E+10	5.70E+10	4.70E+10	1.20E+10	1.70E+08	1.70E+08	1.70E+08	1.70E+08	1.70E+10	1.80E+10	1.70E+08
17	Pasture	2.30E+10	2.90E+10	6.10E+10	5.70E+10	4.10E+10	4.10E+10	4.10E+10	4.10E+10	4.70E+10	4.30E+10	4.30E+10	2.30E+10
17	LDR	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11
17	Forest	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10

Table E6. MON-SQOLIM Table - Monthly limit on surface accumulation of bacteria (cfu/ac). (continued)

Sub-watershed	Land Use	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
18	Crop	1.60E+08	1.50E+10	7.00E+10	5.80E+10	1.40E+10	1.60E+08	1.60E+08	1.60E+08	1.60E+08	2.00E+10	2.20E+10	1.60E+08
18	Pasture	3.20E+10	3.70E+10	7.20E+10	7.30E+10	6.30E+10	6.30E+10	6.30E+10	6.30E+10	6.80E+10	6.30E+10	6.00E+10	3.20E+10
18	LDR	8.00E+10	8.00E+10	8.00E+10	8.00E+10	8.00E+10	8.00E+10	8.00E+10	8.00E+10	8.00E+10	8.00E+10	8.00E+10	8.00E+10
18	Forest	9.10E+08	9.10E+08	6.80E+08	6.80E+08	6.80E+08	6.80E+08	6.80E+08	6.80E+08	9.10E+08	9.10E+08	9.10E+08	9.10E+08
19	Crop	1.60E+08	8.40E+09	3.80E+10	3.10E+10	7.70E+09	1.60E+08	1.60E+08	1.60E+08	1.60E+08	1.10E+10	1.20E+10	1.60E+08
19	Pasture	3.30E+10	3.60E+10	6.00E+10	5.90E+10	5.10E+10	5.10E+10	5.20E+10	5.20E+10	5.50E+10	5.00E+10	4.90E+10	3.20E+10
19	LDR	1.30E+11	1.30E+11	1.30E+11	1.30E+11	1.30E+11	1.30E+11	1.30E+11	1.30E+11	1.30E+11	1.30E+11	1.30E+11	1.30E+11
19	Forest	2.00E+08	2.00E+08	1.90E+08	1.90E+08	1.90E+08	1.90E+08	1.90E+08	1.90E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08
20	Crop	1.60E+08	9.40E+09	4.20E+10	3.50E+10	8.60E+09	1.60E+08	1.60E+08	1.60E+08	1.60E+08	1.30E+10	1.30E+10	1.60E+08
20	Pasture	2.80E+10	3.20E+10	5.70E+10	5.60E+10	4.80E+10	4.90E+10	4.90E+10	4.90E+10	5.20E+10	4.70E+10	4.60E+10	2.70E+10
20	LDR	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11
20	Forest	4.70E+08	4.70E+08	3.80E+08	3.80E+08	3.80E+08	3.80E+08	3.80E+08	3.80E+08	4.70E+08	4.70E+08	4.70E+08	4.70E+08
21	Crop	1.80E+08	1.80E+08	1.80E+08	1.80E+08	1.80E+08	1.80E+08	1.80E+08	1.80E+08	1.80E+08	1.80E+08	1.80E+08	1.80E+08
21	Pasture	6.50E+09	6.50E+09	6.50E+09	6.50E+09	6.50E+09	6.50E+09	6.50E+09	6.50E+09	6.50E+09	6.50E+09	6.50E+09	6.50E+09
21	LDR	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11
21	Forest	3.50E+08	3.50E+08	2.90E+08	2.90E+08	2.90E+08	2.90E+08	2.90E+08	2.90E+08	3.50E+08	3.50E+08	3.50E+08	3.50E+08
22	Crop	2.90E+08	2.90E+08	2.90E+08	2.90E+08	2.90E+08	2.90E+08	2.90E+08	2.90E+08	2.90E+08	2.90E+08	2.90E+08	2.90E+08
22	Pasture	2.90E+08	2.90E+08	2.90E+08	2.90E+08	2.90E+08	2.90E+08	2.90E+08	2.90E+08	2.90E+08	2.90E+08	2.90E+08	2.90E+08
22	LDR	8.80E+10	8.80E+10	8.80E+10	8.80E+10	8.80E+10	8.80E+10	8.80E+10	8.80E+10	8.80E+10	8.80E+10	8.80E+10	8.80E+10
22	Forest	1.90E+08	1.90E+08	1.80E+08	1.80E+08	1.80E+08	1.80E+08	1.80E+08	1.80E+08	1.90E+08	1.90E+08	1.90E+08	1.90E+08
23	Crop	1.60E+08	2.20E+10	1.00E+11	8.40E+10	2.00E+10	1.60E+08	1.60E+08	1.60E+08	1.60E+08	3.10E+10	3.20E+10	1.60E+08
23	Pasture	1.60E+10	2.00E+10	3.90E+10	3.70E+10	2.90E+10	2.90E+10	3.00E+10	3.00E+10	3.30E+10	2.80E+10	2.80E+10	1.60E+10
23	Forest	3.50E+09	3.50E+09	2.30E+09	2.30E+09	2.30E+09	2.30E+09	2.30E+09	2.30E+09	3.50E+09	3.50E+09	3.50E+09	3.50E+09

APPENDIX F.
Fecal Coliform Loading in Sub-Watersheds

Table F-1. Monthly nonpoint fecal coliform loadings in sub-watershed NR-1.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	1,214	91	166
Feb.	11	1,176	83	151
Mar.	54	1,857	91	166
Apr.	43	1,805	88	160
May.	11	1,839	91	166
Jun.	0	1,800	88	160
Jul.	0	1,881	91	166
Aug.	0	1,901	91	166
Sep.	0	1,876	88	160
Oct.	17	1,613	91	166
Nov.	16	1,587	88	160
Dec.	0	1,198	91	166
Total	153	19,748	1,067	1,953

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table F-2. Monthly nonpoint fecal coliform loadings in sub-watershed NR-2.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	1	943	111	47
Feb.	70	913	101	43
Mar.	344	1,439	88	47
Apr.	276	1,398	85	45
May.	70	1,424	88	47
Jun.	1	1,394	85	45
Jul.	1	1,456	88	47
Aug.	1	1,472	88	47
Sep.	1	1,452	107	45
Oct.	106	1,250	111	47
Nov.	106	1,230	107	45
Dec.	1	931	111	47
Total	980	15,300	1,168	550

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table F-3. Monthly nonpoint fecal coliform loadings in sub-watershed NR-3.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	17	21,860	1,015	903
Feb.	1,346	22,925	925	823
Mar.	6,670	41,929	754	903
Apr.	5,339	39,075	730	874
May.	1,348	33,937	754	903
Jun.	16	33,207	730	874
Jul.	17	34,560	754	903
Aug.	17	34,878	754	903
Sep.	16	36,300	982	874
Oct.	2,009	32,396	1,015	903
Nov.	2,041	31,877	982	874
Dec.	17	21,622	1,015	903
Total	18,854	384,567	10,409	10,642

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table F-4. Monthly nonpoint fecal coliform loadings in sub-watershed NR-4.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	12	5,481	139	261
Feb.	393	5,803	127	238
Mar.	1,921	10,849	116	261
Apr.	1,539	10,123	112	253
May.	394	8,809	116	261
Jun.	11	8,633	112	253
Jul.	12	8,997	116	261
Aug.	12	9,091	116	261
Sep.	11	9,465	135	253
Oct.	593	8,270	139	261
Nov.	593	8,153	135	253
Dec.	12	5,410	139	261
Total	5,502	99,085	1,500	3,077

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table F-5. Monthly nonpoint fecal coliform loadings in sub-watershed NR-5.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	26	46,238	1,759	1,149
Feb.	761	45,116	1,603	1,047
Mar.	3,711	75,947	1,238	1,149
Apr.	2,973	72,185	1,198	1,112
May.	763	68,719	1,238	1,149
Jun.	26	67,235	1,198	1,112
Jul.	26	69,112	1,238	1,149
Aug.	26	69,812	1,238	1,149
Sep.	26	70,322	1,702	1,112
Oct.	587	66,073	1,759	1,149
Nov.	1,147	64,839	1,702	1,112
Dec.	26	45,960	1,759	1,149
Total	10,099	761,560	17,631	13,539

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table F-6. Monthly nonpoint fecal coliform loadings in sub-watershed NR-6.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	19	17,212	873	1,429
Feb.	853	19,447	796	1,302
Mar.	4,198	40,470	636	1,429
Apr.	3,362	37,023	616	1,383
May.	855	29,430	636	1,429
Jun.	18	28,877	616	1,383
Jul.	19	30,058	636	1,429
Aug.	19	30,375	636	1,429
Sep.	18	32,719	845	1,383
Oct.	1,291	28,668	873	1,429
Nov.	1,290	28,315	845	1,383
Dec.	19	16,974	873	1,429
Total	11,959	339,567	8,884	16,833

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table F-7. Monthly nonpoint fecal coliform loadings in sub-watershed NR-7.

Month	Fecal Coliform loadings (x10^{10} cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	22	32,251	802	1,372
Feb.	815	32,182	731	1,250
Mar.	3,995	67,137	625	1,372
Apr.	3,200	66,301	605	1,328
May.	817	62,110	625	1,372
Jun.	21	60,414	605	1,328
Jul.	22	62,608	625	1,372
Aug.	22	62,859	625	1,372
Sep.	21	63,270	776	1,328
Oct.	1,005	61,314	802	1,372
Nov.	1,230	56,910	776	1,328
Dec.	22	32,062	802	1,372
Total	11,193	659,417	8,399	16,162

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table F-8. Monthly nonpoint fecal coliform loadings in sub-watershed NR-8.

Month	Fecal Coliform loadings (x10^{10} cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	401	87	40
Feb.	10	387	79	36
Mar.	49	599	87	40
Apr.	39	582	84	39
May.	10	593	87	40
Jun.	0	580	84	39
Jul.	0	606	87	40
Aug.	0	612	87	40
Sep.	0	603	84	39
Oct.	15	523	87	40
Nov.	15	514	84	39
Dec.	0	396	87	40
Total	140	6,396	1,021	471

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table F-9. Monthly nonpoint fecal coliform loadings in sub-watershed NR-9.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	9	546	92	28
Feb.	255	845	84	26
Mar.	1,242	2,416	92	28
Apr.	995	2,077	89	27
May.	255	1,149	92	28
Jun.	8	1,132	89	27
Jul.	9	1,168	92	28
Aug.	9	1,178	92	28
Sep.	8	1,481	89	27
Oct.	384	1,359	92	28
Nov.	384	1,348	89	27
Dec.	9	539	92	28
Total	3,565	15,239	1,089	335

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table F-10. Monthly nonpoint fecal coliform loadings in sub-watershed NR-10.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	17	18,629	140	636
Feb.	1,193	21,882	128	579
Mar.	5,904	49,862	140	636
Apr.	4,726	44,897	136	615
May.	1,194	33,249	140	636
Jun.	16	32,424	136	615
Jul.	17	33,604	140	636
Aug.	17	33,845	140	636
Sep.	16	37,511	136	615
Oct.	1,722	34,736	140	636
Nov.	1,808	34,198	136	615
Dec.	17	18,448	140	636
Total	16,649	393,286	1,652	7,488

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table F-11. Monthly nonpoint fecal coliform loadings in sub-watershed NR-11.

Month	Fecal Coliform loadings (x10^{10} cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	10	3,435	94	218
Feb.	577	3,797	86	198
Mar.	2,852	8,912	94	218
Apr.	2,283	8,632	91	211
May.	578	7,206	94	218
Jun.	9	7,030	91	211
Jul.	10	7,285	94	218
Aug.	10	7,325	94	218
Sep.	9	7,706	91	211
Oct.	840	7,301	94	218
Nov.	874	6,712	91	211
Dec.	10	3,405	94	218
Total	8,060	78,748	1,112	2,563

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table F-12. Monthly nonpoint fecal coliform loadings in sub-watershed NR-12.

Month	Fecal Coliform loadings (x10^{10} cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	13	2,930	123	1,529
Feb.	510	2,838	112	1,394
Mar.	2,504	4,466	123	1,529
Apr.	2,005	4,340	119	1,480
May.	511	4,422	123	1,529
Jun.	13	4,328	119	1,480
Jul.	13	4,520	123	1,529
Aug.	13	4,570	123	1,529
Sep.	13	4,508	119	1,480
Oct.	771	3,881	123	1,529
Nov.	771	3,819	119	1,480
Dec.	13	2,893	123	1,529
Total	7,150	47,514	1,445	18,018

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table F-13. Monthly nonpoint fecal coliform loadings in sub-watershed NR-13.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	23	35,348	153	605
Feb.	919	35,496	139	551
Mar.	4,515	65,350	116	605
Apr.	3,616	62,866	112	585
May.	921	55,907	116	605
Jun.	22	54,251	112	585
Jul.	23	56,096	116	605
Aug.	23	56,229	116	605
Sep.	22	57,643	148	585
Oct.	1,097	57,293	153	605
Nov.	1,389	53,847	148	585
Dec.	23	35,247	153	605
Total	12,593	625,575	1,583	7,123

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table F-14. Monthly nonpoint fecal coliform loadings in sub-watershed NR-14.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	11	7,999	41	153
Feb.	960	7,978	37	140
Mar.	4,758	15,769	32	153
Apr.	3,808	14,821	31	148
May.	961	13,559	32	153
Jun.	11	13,180	31	148
Jul.	11	13,643	32	153
Aug.	11	13,686	32	153
Sep.	11	13,881	40	148
Oct.	1,346	13,632	41	153
Nov.	1,455	13,282	40	148
Dec.	11	7,966	41	153
Total	13,354	149,396	431	1,806

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table F-15. Monthly nonpoint fecal coliform loadings in sub-watershed NR-15.

Month	Fecal Coliform loadings (x10^{10} cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	2	5,178	84	46
Feb.	45	5,476	76	42
Mar.	222	13,840	58	46
Apr.	178	13,653	56	44
May.	46	11,724	58	46
Jun.	2	11,383	56	44
Jul.	2	11,651	58	46
Aug.	2	11,693	58	46
Sep.	2	12,171	81	44
Oct.	35	12,448	84	46
Nov.	69	11,241	81	44
Dec.	2	5,178	84	46
Total	604	125,636	832	542

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table F-16. Monthly nonpoint fecal coliform loadings in sub-watershed NR-17.

Month	Fecal Coliform loadings (x10^{10} cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	8	1,191	298	708
Feb.	594	2,030	272	645
Mar.	2,939	5,916	220	708
Apr.	2,352	4,932	213	685
May.	594	2,136	220	708
Jun.	8	2,097	213	685
Jul.	8	2,136	220	708
Aug.	8	2,136	220	708
Sep.	8	3,042	288	685
Oct.	900	3,081	298	708
Nov.	900	3,042	288	685
Dec.	8	1,191	298	708
Total	8,329	32,928	3,048	8,340

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table F-17. Monthly nonpoint fecal coliform loadings in sub-watershed NR-18.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	45	44,041	383	1,549
Feb.	3,983	45,830	349	1,411
Mar.	19,753	98,745	287	1,549
Apr.	15,810	96,312	278	1,499
May.	3,987	85,432	287	1,549
Jun.	44	83,057	278	1,499
Jul.	45	86,077	287	1,549
Aug.	45	86,482	287	1,549
Sep.	44	89,010	370	1,499
Oct.	5,707	85,366	383	1,549
Nov.	6,041	79,172	370	1,499
Dec.	45	43,736	383	1,549
Total	55,548	923,259	3,944	18,248

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table F-18. Monthly nonpoint fecal coliform loadings in sub-watershed NR-19.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	22	32,402	329	1,080
Feb.	1,075	33,093	300	984
Mar.	5,295	59,606	312	1,080
Apr.	4,239	57,015	302	1,045
May.	1,077	50,904	312	1,080
Jun.	21	49,470	302	1,045
Jul.	22	51,373	312	1,080
Aug.	22	51,715	312	1,080
Sep.	21	53,325	319	1,045
Oct.	1,533	49,616	329	1,080
Nov.	1,626	47,378	319	1,045
Dec.	22	32,144	329	1,080
Total	14,975	568,039	3,778	12,726

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table F-19. Monthly nonpoint fecal coliform loadings in sub-watershed NR-20.

Month	Fecal Coliform loadings (x10^{10} cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	42	31,464	1,086	2,051
Feb.	2,249	32,806	990	1,869
Mar.	11,096	65,059	867	2,051
Apr.	8,884	61,862	839	1,985
May.	2,252	54,753	867	2,051
Jun.	40	53,352	839	1,985
Jul.	42	55,435	867	2,051
Aug.	42	55,841	867	2,051
Sep.	40	57,708	1,051	1,985
Oct.	3,344	53,095	1,086	2,051
Nov.	3,404	51,009	1,051	1,985
Dec.	42	31,158	1,086	2,051
Total	31,476	603,542	11,500	24,166

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table F-20. Monthly nonpoint fecal coliform loadings in sub-watershed NR-21.

Month	Fecal Coliform loadings (x10^{10} cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	1	193	2,344	795
Feb.	1	176	2,136	725
Mar.	1	193	1,947	795
Apr.	1	186	1,884	770
May.	1	193	1,947	795
Jun.	1	186	1,884	770
Jul.	1	193	1,947	795
Aug.	1	193	1,947	795
Sep.	1	186	2,268	770
Oct.	1	193	2,344	795
Nov.	1	186	2,268	770
Dec.	1	193	2,344	795
Total	7	2,271	25,256	9,370

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table F-21. Monthly nonpoint fecal coliform loadings in sub-watershed NR-22.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	1	5	2,755	47
Feb.	0	4	2,510	43
Mar.	1	5	2,631	47
Apr.	0	5	2,546	45
May.	1	5	2,631	47
Jun.	0	5	2,546	45
Jul.	1	5	2,631	47
Aug.	1	5	2,631	47
Sep.	0	5	2,666	45
Oct.	1	5	2,755	47
Nov.	0	5	2,666	45
Dec.	1	5	2,755	47
Total	6	56	31,722	552

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table F-22. Monthly nonpoint fecal coliform loadings in sub-watershed NR-23.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	1	1,212	75	47
Feb.	184	1,364	69	43
Mar.	914	2,866	49	47
Apr.	731	2,637	48	46
May.	184	2,151	49	47
Jun.	1	2,107	48	46
Jul.	1	2,196	49	47
Aug.	1	2,221	49	47
Sep.	1	2,377	73	46
Oct.	279	2,046	75	47
Nov.	279	2,024	73	46
Dec.	1	1,193	75	47
Total	2,579	24,395	733	556

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

APPENDIX G.
Required Reductions in Fecal Coliform Loads by Sub-Watershed – Allocation Scenario

Table G-1a. Required annual reductions in nonpoint sources in sub-watershed NR-1.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	15,295	0.7%	1,529	90%
Pasture	1,974,771	86%	197,477	90%
Forest	106,739	5%	106,739	0%
Residential	195,263	9%	19,526	90%
Total	2,292,068	100%	325,272	86%

Table G-1b. Required annual reductions in direct nonpoint sources in sub-watershed NR-1.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	283	4%	141	50%
Wildlife in Streams	7,185	96%	7,185	0%
Straight Pipes	0	0%	0	100%
Total	7,468	100%	7,326	2%

Table G-2a. Required annual reductions in nonpoint sources in sub-watershed NR-2.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	97,951	5%	9,795	90%
Pasture	1,530,001	85%	153,000	90%
Forest	116,809	6%	116,809	0%
Residential	55,007	3%	5,501	90%
Total	1,799,768	100%	285,105	84%

Table G-2b. Required annual reductions in direct nonpoint sources in sub-watershed NR-2.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	217	3%	109	50%
Wildlife in Streams	7,921	97%	7,921	0%
Straight Pipes	0	0%	0	100%
Total	8,138	100%	8,030	1%

Table G-3a. Required annual reductions in nonpoint sources in sub-watershed NR-3.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	1,885,358	4%	188,536	90%
Pasture	38,456,679	91%	3,845,669	90%
Forest	1,040,890	2%	1,040,890	0%
Residential	1,064,156	3%	106,416	90%
Total	42,447,083	100%	5,181,510	88%

Table G-3b. Required annual reductions in direct nonpoint sources in sub-watershed NR-3.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	11,754	15%	5,877	50%
Wildlife in Streams	67,427	85%	67,427	0%
Straight Pipes	0	0%	0	100%
Total	79,181	100%	73,304	7%

Table G-4a. Required annual reductions in nonpoint sources in sub-watershed NR-4.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	550,238	5%	55,024	90%
Pasture	9,908,495	91%	990,850	90%
Forest	150,019	1%	150,019	0%
Residential	307,723	3%	30,772	90%
Total	10,916,475	100%	1,226,665	89%

Table G-4b. Required annual reductions in direct nonpoint sources in sub-watershed NR-4.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	1,283	12%	641	50%
Wildlife in Streams	9,519	88%	9,519	0%
Straight Pipes	0	0%	0	100%
Total	10,802	100%	10,160	6%

Table G-5a. Required annual reductions in nonpoint sources in sub-watershed NR-5.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	1,009,924	1%	100,992	90%
Pasture	76,155,959	95%	7,615,598	90%
Forest	1,763,075	2%	1,763,075	0%
Residential	1,353,945	2%	135,395	90%
Total	80,282,903	100%	9,615,060	88%

Table G-5b. Required annual reductions in direct nonpoint sources in sub-watershed NR-5.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	18,268	14%	9,134	50%
Wildlife in Streams	114,724	86%	114,724	0%
Straight Pipes	0	0%	0	100%
Total	132,992	100%	123,858	7%

Table G-6a. Required annual reductions in nonpoint sources in sub-watershed NR-6.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	1,195,939	3%	119,594	90%
Pasture	33,956,742	90%	3,395,675	90%
Forest	888,378	2%	888,378	0%
Residential	1,683,291	4%	168,329	90%
Total	37,724,350	100%	4,571,976	88%

Table G-6b. Required annual reductions in direct nonpoint sources in sub-watershed NR-6.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	4,304	7%	2,152	50%
Wildlife in Streams	54,603	93%	54,603	0%
Straight Pipes	0	0%	0	100%
Total	58,907	100%	56,755	4%

Table G-7a. Required annual reductions in nonpoint sources in sub-watershed NR-7.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	1,119,313	2%	111,931	90%
Pasture	65,941,679	95%	6,594,169	90%
Forest	839,869	1%	839,869	0%
Residential	1,616,231	2%	161,623	90%
Total	69,517,092	100%	7,707,593	89%

Table G-7b. Required annual reductions in direct nonpoint sources in sub-watershed NR-7.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	3,413	6%	1,706	50%
Wildlife in Streams	52,465	94%	52,465	0%
Straight Pipes	0	0%	0	100%
Total	55,878	100%	54,172	3%

Table G-8a. Required annual reductions in nonpoint sources in sub-watershed NR-8.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	14,016	2%	1,402	90%
Pasture	639,586	80%	63,959	90%
Forest	102,088	13%	102,088	0%
Residential	47,117	6%	4,712	90%
Total	802,808	100%	172,160	79%

Table G-8b. Required annual reductions in direct nonpoint sources in sub-watershed NR-8.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	87	1%	43	50%
Wildlife in Streams	6,843	99%	6,843	0%
Straight Pipes	0	0%	0	100%
Total	6,930	100%	6,886	1%

Table G-9a. Required annual reductions in nonpoint sources in sub-watershed NR-9.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	356,549	18%	35,655	90%
Pasture	1,523,866	75%	152,387	90%
Forest	108,857	5%	108,857	0%
Residential	33,457	2%	3,346	90%
Total	2,022,729	100%	300,245	85%

Table G-9b. Required annual reductions in direct nonpoint sources in sub-watershed NR-9.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	130	2%	65	50%
Wildlife in Streams	7,467	98%	7,467	0%
Straight Pipes	0	0%	0	100%
Total	7,597	100%	7,532	1%

Table G-10a. Required annual reductions in nonpoint sources in sub-watershed NR-10.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	1,664,890	4%	166,489	90%
Pasture	39,328,608	94%	3,932,862	90%
Forest	165,159	0.4%	165,159	0%
Residential	748,836	2%	74,884	90%
Total	41,907,493	100%	4,339,394	90%

Table G-10b. Required annual reductions in direct nonpoint sources in sub-watershed NR-10.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	113,177	94%	56,588	50%
Wildlife in Streams	7,814	6%	7,814	0%
Straight Pipes	0	0%	0	100%
Total	120,991	100%	64,402	47%

Table G-11a. Required annual reductions in nonpoint sources in sub-watershed NR-11.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	806,039	9%	80,604	90%
Pasture	7,874,821	87%	787,482	90%
Forest	111,234	1%	111,234	0%
Residential	256,296	3%	25,630	90%
Total	9,048,390	100%	1,004,950	89%

Table G-11b. Required annual reductions in direct nonpoint sources in sub-watershed NR-11.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	543	6%	272	50%
Wildlife in Streams	8,008	94%	8,008	0%
Straight Pipes	0	0%	0	100%
Total	8,551	100%	8,280	3%

Table G-12a. Required annual reductions in nonpoint sources in sub-watershed NR-12.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	714,970	10%	71,497	90%
Pasture	4,751,445	64%	475,145	90%
Forest	144,536	2%	144,536	0%
Residential	1,801,815	24%	180,182	90%
Total	7,412,765	100%	871,359	88%

Table G-12b. Required annual reductions in direct nonpoint sources in sub-watershed NR-12.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	674	8%	337	50%
Wildlife in Streams	8,297	92%	8,297	0%
Straight Pipes	0	0%	0	100%
Total	8,971	100%	8,634	4%

Table G-13a. Required annual reductions in nonpoint sources in sub-watershed NR-13.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	1,259,303	2%	125,930	90%
Pasture	62,557,518	97%	6,255,753	90%
Forest	158,332	0.2%	158,332	0%
Residential	712,347	1%	71,235	90%
Total	64,687,500	100%	6,611,250	90%

Table G-13b. Required annual reductions in direct nonpoint sources in sub-watershed NR-13.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	69,517	78%	34,759	50%
Wildlife in Streams	19,796	22%	19,796	0%
Straight Pipes	0	0%	0	100%
Total	89,314	100%	54,555	39%

Table G-14a. Required annual reductions in nonpoint sources in sub-watershed NR-14.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	1,335,442	8%	133,544	90%
Pasture	14,939,603	91%	1,493,961	90%
Forest	43,101	0.3%	43,101	0%
Residential	180,580	1%	18,058	90%
Total	16,498,725	100%	1,688,664	90%

Table G-14b. Required annual reductions in direct nonpoint sources in sub-watershed NR-14.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	2,348	29%	1,174	50%
Wildlife in Streams	5,771	71%	5,771	0%
Straight Pipes	0	0%	0	100%
Total	8,118	100%	6,945	14%

Table G-15a. Required annual reductions in nonpoint sources in sub-watershed NR-15.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	60,358	0.5%	6,036	90%
Pasture	12,563,576	98%	1,256,358	90%
Forest	83,240	0.7%	83,240	0%
Residential	54,167	0.4%	5,417	90%
Total	12,761,340	100%	1,351,050	89%

Table G-15b. Required annual reductions in direct nonpoint sources in sub-watershed NR-15.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	26,828	70%	13,414	50%
Wildlife in Streams	11,494	30%	11,494	0%
Straight Pipes	0	0%	0	100%
Total	38,322	100%	24,908	35%

Table G-16a. Required annual reductions in nonpoint sources in sub-watershed NR-17.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	832,930	16%	83,293	90%
Pasture	3,292,761	63%	329,276	90%
Forest	304,795	6%	304,795	0%
Residential	834,012	16%	83,401	90%
Total	5,264,498	100%	800,766	85%

Table G-16b. Required annual reductions in direct nonpoint sources in sub-watershed NR-17.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	0	0%	0	50%
Wildlife in Streams	35,587	100%	35,587	0%
Straight Pipes	0	0%	0	100%
Total	35,587	100%	35,587	0%

Table G-17a. Required annual reductions in nonpoint sources in sub-watershed NR-18.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	5,554,808	6%	555,481	90%
Pasture	92,325,924	92%	9,232,595	90%
Forest	394,385	0.4%	394,385	0%
Residential	1,824,752	2%	182,475	90%
Total	100,099,870	100%	10,364,936	90%

Table G-17b. Required annual reductions in direct nonpoint sources in sub-watershed NR-18.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	144,147	68%	72,074	50%
Wildlife in Streams	46,529	22%	46,529	0%
Straight Pipes	21,111	10%	0	100%
Total	211,788	100%	118,603	44%

Table G-18a. Required annual reductions in nonpoint sources in sub-watershed NR-19.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	1,497,453	2%	149,745	90%
Pasture	56,803,870	95%	5,680,388	90%
Forest	377,754	0.6%	377,754	0%
Residential	1,272,604	2%	127,260	90%
Total	59,951,681	100%	6,335,148	89%

Table G-18b. Required annual reductions in direct nonpoint sources in sub-watershed NR-19.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	190,309	86%	95,155	50%
Wildlife in Streams	11,491	5%	11,491	0%
Straight Pipes	20,162	9%	0	100%
Total	221,962	100%	106,645	52%

Table G-19a. Required annual reductions in nonpoint sources in sub-watershed NR-20.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	3,147,619	5%	314,762	90%
Pasture	60,354,206	90%	6,035,422	90%
Forest	1,149,969	2%	1,149,969	0%
Residential	2,416,567	4%	241,657	90%
Total	67,068,360	100%	7,741,809	88%

Table G-19b. Required annual reductions in direct nonpoint sources in sub-watershed NR-20.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	115,425	48%	57,712	50%
Wildlife in Streams	103,438	43%	103,438	0%
Straight Pipes	19,504	8%	0	100%
Total	238,368	100%	161,151	32%

Table G-20a. Required annual reductions in nonpoint sources in sub-watershed NR-21.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	683	0%	68	90%
Pasture	227,053	6%	22,705	90%
Forest	2,525,610	68%	2,525,610	0%
Residential	936,976	25%	93,698	90%
Total	3,690,322	100%	2,642,081	28%

Table G-20b. Required annual reductions in direct nonpoint sources in sub-watershed NR-21.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	0	0%	0	50%
Wildlife in Streams	183,659	90%	183,659	0%
Straight Pipes	21,258	10%	0	100%
Total	204,917	100%	183,659	10%

Table G-21a. Required annual reductions in nonpoint sources in sub-watershed NR-22.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	601	0%	60	90%
Pasture	5,610	0.2%	561	90%
Forest	3,172,177	98%	3,172,177	0%
Residential	55,153	2%	5,515	90%
Total	3,233,540	100%	3,178,313	2%

Table G-21b. Required annual reductions in direct nonpoint sources in sub-watershed NR-22.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	0	0%	0	50%
Wildlife in Streams	77,569	100%	77,569	0%
Straight Pipes	0	0%	0	100%
Total	77,569	100%	77,569	0%

Table G-22a. Required annual reductions in nonpoint sources in sub-watershed NR-23.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	257,866	9%	25,787	90%
Pasture	2,439,467	86%	243,947	90%
Forest	73,303	3%	73,303	0%
Residential	55,591	2%	0	100%
Total	2,826,228	100%	343,036	88%

Table G-22b. Required annual reductions in direct nonpoint sources in sub-watershed NR-23.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	5,217	34%	2,609	50%
Wildlife in Streams	10,013	66%	10,013	0%
Straight Pipes	0	0%	0	100%
Total	15,230	100%	12,622	17%

APPENDIX H.
Simulated Stream Flow Chart for TMDL Allocation Period

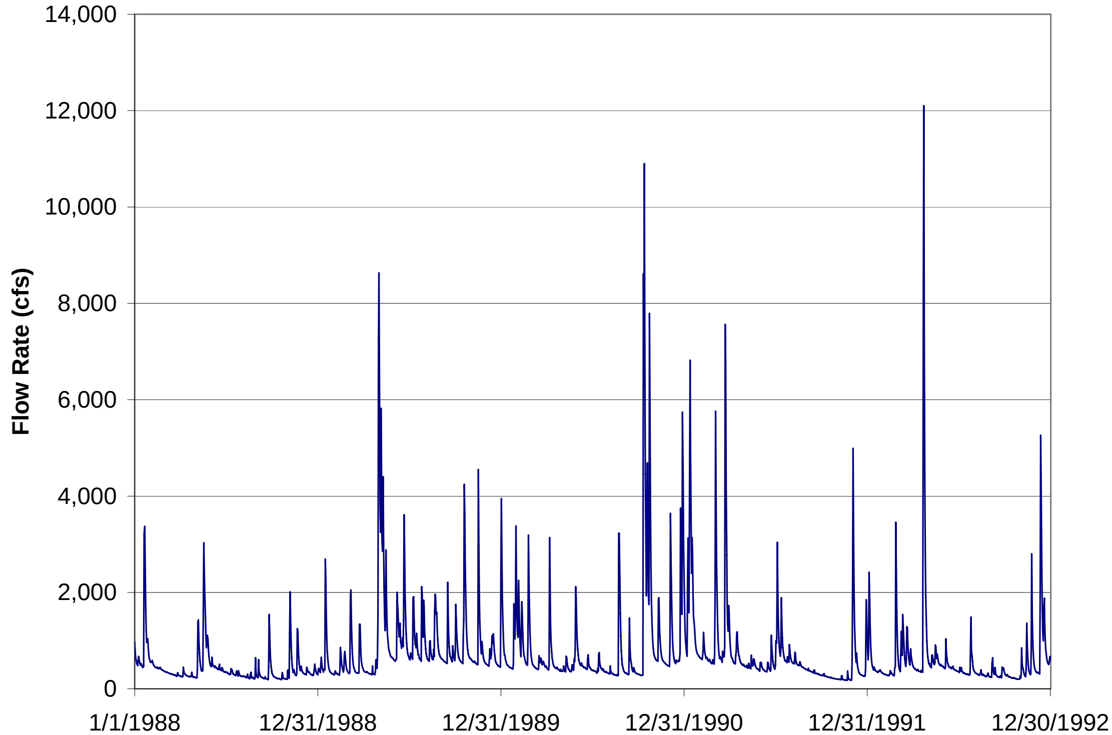

Figure H.1. Simulated Stream Flow for North River TMDL Allocation Period.

APPENDIX I.
Observed Fecal Coliform Concentrations and Antecedent Rainfall

Table I.1. Observed fecal coliform concentrations and antecedent rainfall for station 1BNTH014.08 on North River during the calibration period.

Date	Fecal Coliform (cfu/100 mL)	Total Rainfall for Sampling Day and Preceding 5 Days (inches)
9/20/1993	200	5.4
10/20/1993	1200	0.8
11/22/1993	100	0.5
12/15/1993	200	0.3
1/26/1994	4400	0.1
2/15/1994	300	1.6
3/16/1994	100	0
4/12/1994	500	0.3
5/17/1994	2300	0
6/30/1994	600	0.9
7/27/1994	2100	0.9
8/17/1994	8000	2.7
9/19/1994	200	0.2
10/13/1994	400	0
11/16/1994	600	0.2
12/20/1994	100	0.2
1/17/1995	900	1.6
2/23/1995	500	0.5

APPENDIX J.
CAFOs in the North River Watershed

Table J.1. Permitted Poultry CAFOs in North River.

Permit Number	Bird Type	Subwatershed	Permit Number	Bird Type	Subwatershed
VPG260011	Turkey	NR-20	VPG260454	Broiler	NR-19
VPG260038	Turkey	NR-17	VPG260455	Turkey	NR-20
VPG260061	Turkey	NR-05	VPG260456	Turkey	NR-20
VPG260064	Broiler	NR-10	VPG260457	Broiler	NR-11
VPG260072	Broiler	NR-20	VPG260464	Broiler	NR-14
VPG260078	Broiler	NR-18	VPG260496	Broiler	NR-11
VPG260087	Broiler	NR-18	VPG260511	Broiler	NR-13
VPG260093	Broiler	NR-18	VPG260540	Broiler	NR-06
VPG260111	Turkey	NR-19	VPG260541	Broiler	NR-03
VPG260132	Turkey	NR-19	VPG260556	Turkey	NR-07
VPG260140	Turkey	NR-20	VPG260568	Broiler	NR-10
VPG260152	Turkey	NR-18	VPG260573	Broiler	NR-17
VPG260155	Turkey	NR-05	VPG260579	Broiler	NR-10
VPG260177	Pullet	NR-10	VPG260586	Broiler	NR-18
VPG260184	Turkey	NR-06	VPG260607	Turkey	NR-06
VPG260191	Turkey	NR-10	VPG260613	Turkey	NR-03
VPG260201	Turkey	NR-05	VPG260616	Broiler	NR-15
VPG260215	Turkey	NR-13	VPG260622	Broiler	NR-10
VPG260228	Broiler	NR-18	VPG260639	Broiler	NR-19
VPG260245	Turkey	NR-07	VPG260646	Turkey	NR-10
VPG260251	Turkey	NR-06	VPG260662	Broiler	NR-18
VPG260291	Broiler	NR-07	VPG260668A	Broiler	NR-18
VPG260335	Broiler	NR-13	VPG260668B	Turkey	NR-13
VPG260347	Turkey	NR-19	VPG260692	Turkey	NR-13
VPG260351	Broiler	NR-09	VPG260694	Broiler	NR-18
VPG260358	Broiler	NR-13	VPG260706	Turkey	NR-09
VPG260359	Broiler	NR-13	VPG260716	Turkey	NR-07
VPG260367	Broiler	NR-18	VPG260724	Broiler	NR-03
VPG260375	Turkey	NR-04	VPG260730	Turkey	NR-19
VPG260397	Broiler	NR-06	VPG260744	Broiler	NR-20
VPG260413	Turkey	NR-13	VPG260751	Broiler	NR-23

Table J.2. Permitted Non-Poultry CAFOs in North River

Permit Number	Animal Type	Subwatershed
VPG160021	Dairy	NR-05
VPG160022	Dairy	NR-07
VPG160040	Dairy	NR-05

APPENDIX K.
Scenarios for Fivefold Increase in Permitted Discharge Flows

To allow for future growth, a scenario was created for North River in which the point source flows were increased by a factor of 5, while retaining the 200 cfu/100 mL limit on bacteria. This effectively increased the point source portion of the WLA by a factor of 5. The MS4 WLA was not altered. Figure K.1 displays the results. The TMDL equation that would represent this situation is included in Table K.1.

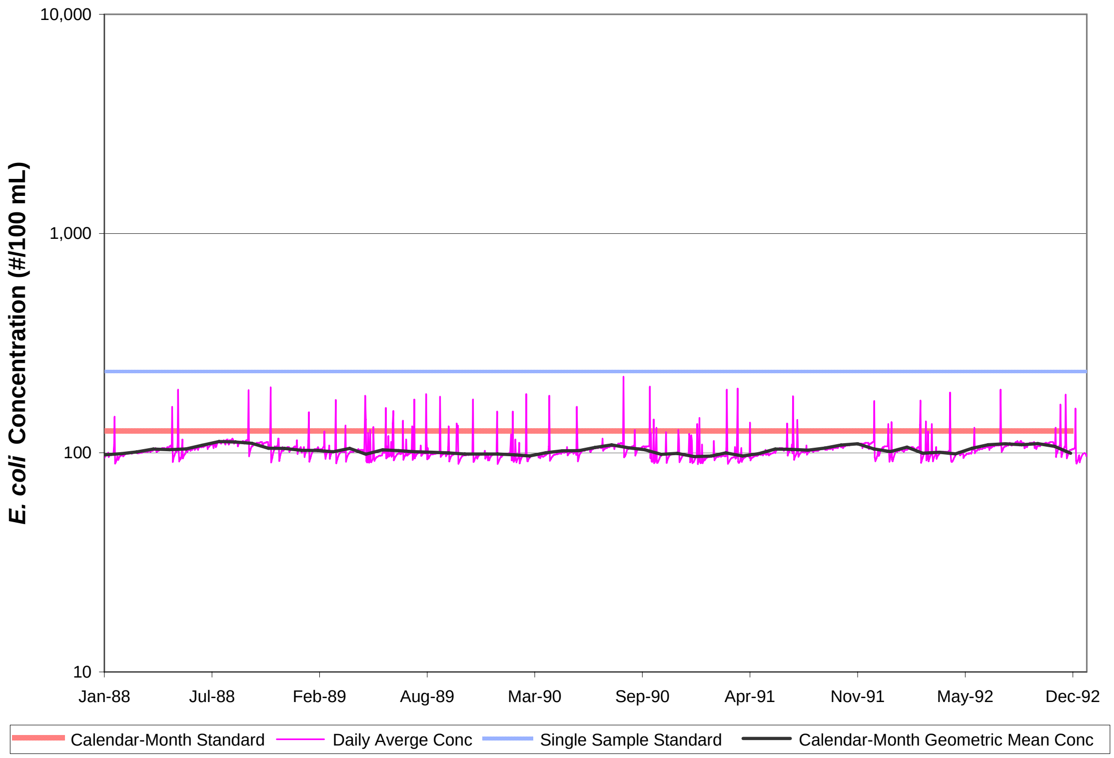

Figure K.1. Daily average and calendar-month geometric mean *E. coli* concentration in North River under the fivefold WLA increase scenario.

Table K.1. Average annual *E. coli* loadings (cfu/year) at the watershed outlet for North River under the fivefold WLA increase scenario.

ΣWLA	ΣLA	TMDL
2.48×10^{14}	1.10×10^{14}	3.58×10^{14}

As can be seen from Figure K.1, the new scenario results in no violations of the instantaneous or geometric mean standards. Therefore, it is assumed that future growth in point source dischargers with a consistent permitted bacteria concentration of 200 cfu/100 mL fecal coliform will not cause additional violations of the water quality standards.

APPENDIX L.
Karst Hydrogeology of the North River Watershed

This appendix includes a summary of the current state of knowledge of the karst hydrology of the North River Watershed.

Springs emerging from carbonate bedrock (karst springs) occur throughout the watershed, and are essentially the sole source of the stream during late summer through early autumn.

The springs are fed either by:

a) large streams (North River, Briery Branch, Dry River) that sink as they flow onto the carbonate bedrock from the Alleghany mountains to the west (e.g. – Mt. Solon Spring, Beaver Creek Spring, Spring Creek Spring), or

b) diffuse recharge into the carbonate aquifer that converges along high permeability fractures and faults and reemerges at the surface at large, consistently high flow springs (Cress Pond, Silver Lake, possibly Kyle's Mill).

Figure L.1 shows some of these springs, sinkpoints, and possible connections.

Not all springs have yet been fit into this classification system, and the dye tracing needs to be completed to determine the specific connections between the sinking surface streams and the large springs along the western side of the valley. The dynamics of these aquifer systems may turn out to be complex, and may place limitations on the time scale over which implemented pollutant reduction measures will produce a measurable improvement in water quality, depending on the parameters measured. The western part of the valley includes a very coarse-grained porous media aquifer infilling an older karst landscape. In places the infilling material has been washed away, and the system behaves like a normal, high velocity conduit flow karst system. In other areas, the system will be more complex.

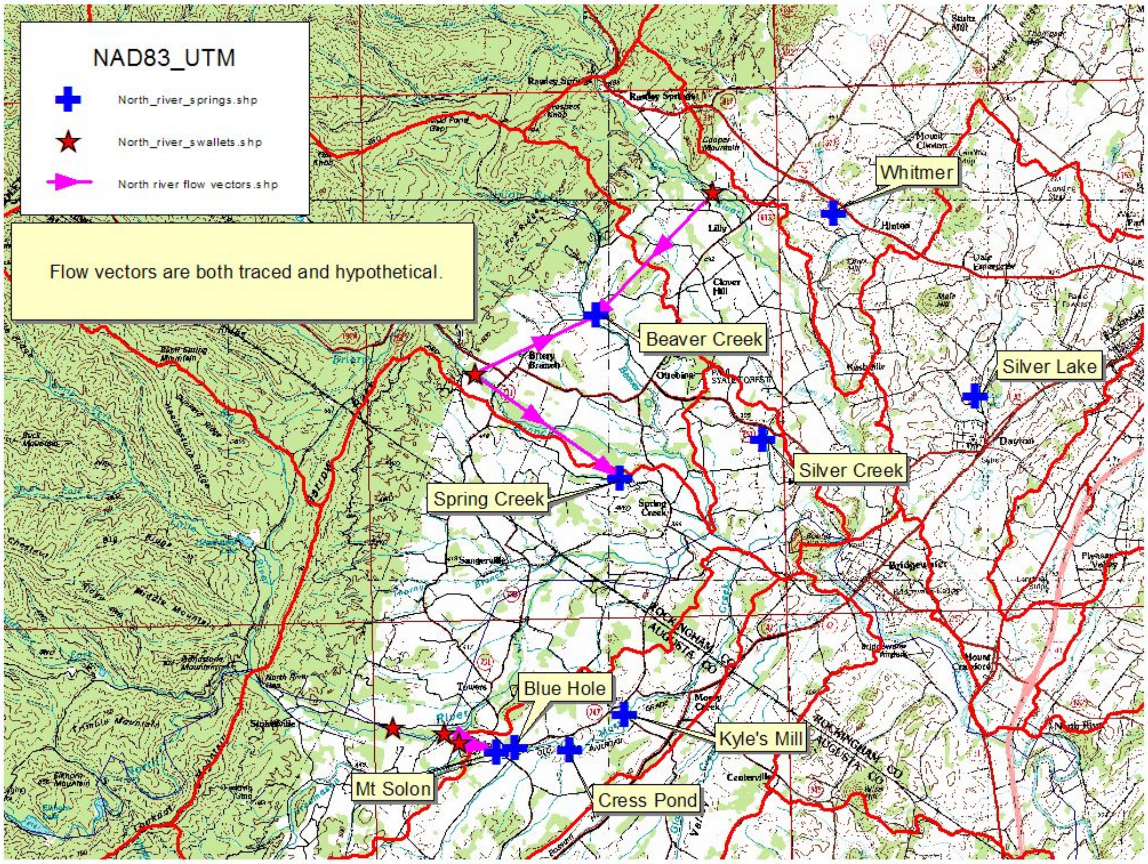

Figure L.1. North River springs, sinkpoints, and possible connections.

The DCR Karst Program will be working with DEQ and Virginia Tech to better characterize and delineate the karst groundwater systems that form the headwaters of the North River basin.